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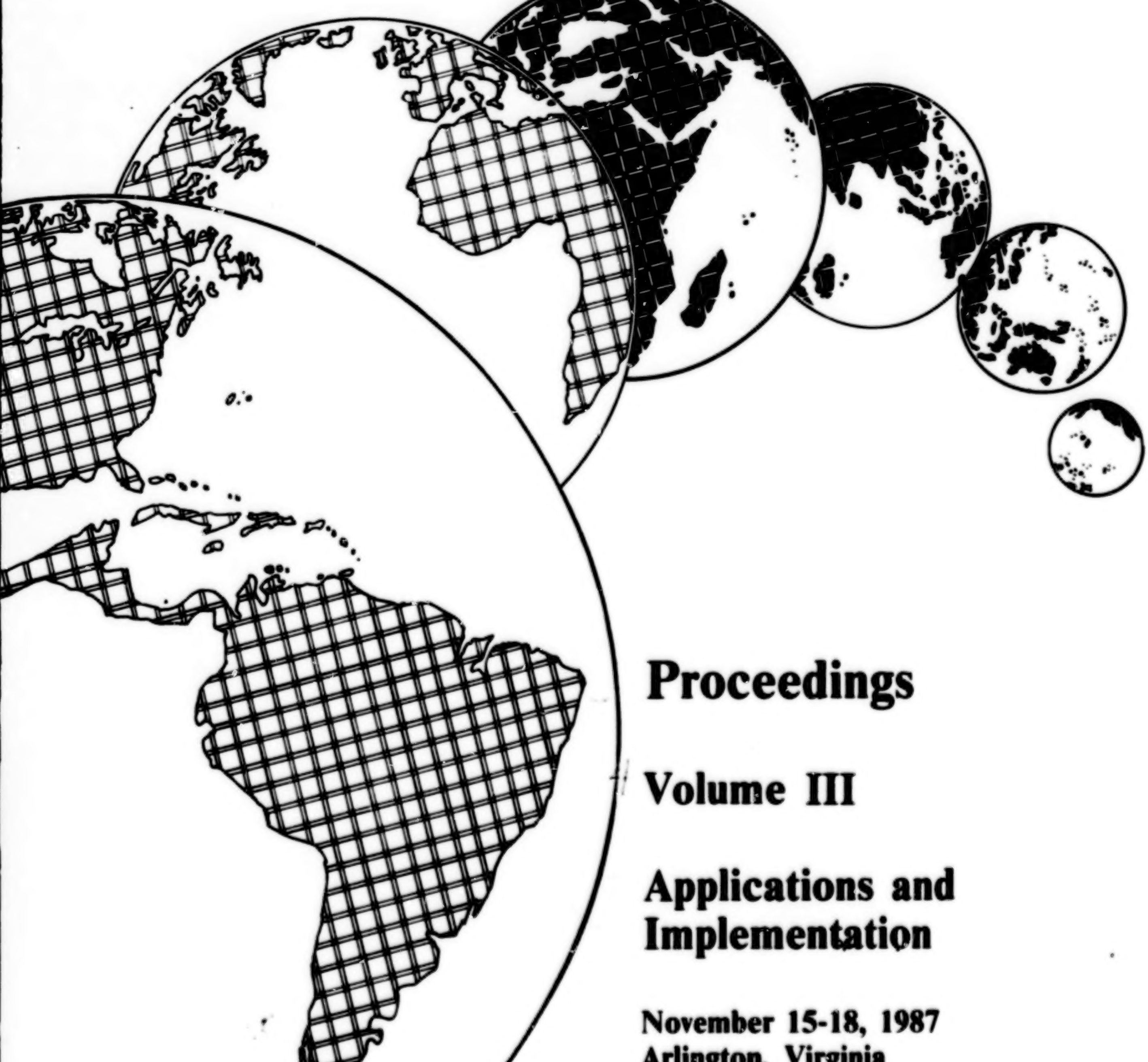
International Geographic Information Systems (IGIS) Symposium: The Research Agenda



Proceedings

Volume III

Applications and Implementation

November 15-18, 1987
Arlington, Virginia

NASA
National Aeronautics and Space Administration

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INTERNATIONAL GEOGRAPHIC INFORMATION SYSTEMS (IGIS) SYMPOSIUM

The Research Agenda

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Proceedings

Volume III

Applications and Implementation

Dr. Robert T. Aangeenbrug, Co-Editor
Yale M. Schiffman, Co-Editor

Convened by the

Association of American Geographers

In Cooperation with
National Aeronuatics and Space Administration
Bureau of Land Management
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U.S. Geological Survey
Defense Mapping Agency
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Marine Technology Society
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PREFACE

These proceedings contain a selection of papers presented at the Association of American Geographers' (AAG) International Geographic Information Systems (IGIS) Symposium which was held at the Hyatt Regency Crystal City Hotel in Arlington, VA, on November 16-18, 1987. The papers cover a wide variety of subject areas related to the conference theme, "The Research Agenda," and describe the current status and future direction of geographic information systems and their application to a number of resource management concerns.

The symposium brought together professionals in such diverse fields as remote sensing, geographic information systems, data base management systems, information systems, urban and regional planning, fish and wildlife management, geography, cartography, artificial intelligence, systems analysis, and resource management. The speakers and audience had an international flavor with representatives from South America, Africa, Europe, Canada, Asia, and the United States. In all, nearly 500 professionals met to exchange information and ideas regarding the role and the research needs and agenda for the development of the next generation of geographic information systems. Fifty exhibit booths displayed the latest geographic information systems hardware, software, and services.

On Monday, November 16, nearly all of the federal agencies involved in the design and development of GIS presented their respective views on agency needs in a plenary session chaired by Ronald F. Abler, National Science Foundation. The policy perspective was provided by Paul Huray, Office of Science and Technology, and Robert Lee Chartrand, Congressional Research Service. The National Aeronautics and Space Administration, the Bureau of Land Management, the National Oceanic and Atmospheric Association, the U.S. Geological Survey, the Defense Mapping Agency, the USETL, the Federal Emergency Management Agency, the Bureau of the Census, the U.S. Department of Agriculture/Forest Service, and the Environmental Protection Agency were all represented. That afternoon, a plenary session chaired by David Cowens, University of South Carolina, explored the GIS research agenda from the perspective of the scientific community.

On Tuesday, November 17, a panel chaired by Michael Dobson, Rand McNally and Company, presented an overview of the trends in hardware and software development of GIS. This plenary session provided the industry view of where GIS seems to be heading. On Wednesday, November 18, a plenary session chaired by Duane Marble, Ohio State University, explored the cutting edge of GIS development in terms of spatial analysis and artificial intelligence. The final plenary session examined some of the practical aspects of GIS management and implementation in a session chaired by William J. Craig, University of Minnesota.

Three keynote addresses were given on Tuesday, November 17,

at a well attended luncheon. Roger Chorley, President of the U.K.'s Royal Geographic Society, Dallas Peck, Director of the USGS, and Roger Tomlinson, President of the Canadian Association of Geographers, gave enlightening perspectives on where GIS has been and what is in its future.

The keynote addresses, as well as the plenary sessions, can be found in Volume I.

The meeting closed on a positive note, indicating that there was, indeed, a need to continue dialog by specialists from this wide array of interests. The emphasis should be on improving the communication between the user community and the software, hardware, and analytical support specialists in the field. Thus, this meeting serves as the starting point for a continuing series on the subject.

The interdisciplinary oriented symposium provided a forum for presenting and discussing scientific works in the areas of energy resource management, remote sensing, geographic information systems, other georeferenced data systems, environmental analysis, and applied systems research. Nearly 125 scientists, engineers, planners, and other professionals from around the world contributed to these proceeding.

The proceedings have been organized along subject lines rather than in order of presentation. The editors felt the information would be more useful to the reader if it were organized in this fashion. In Volume I, these papers examine a general overview of the state of the art. Volume II examines the technical issues. In Volume III, the papers explore the topic from an applications focus. Many papers also explore the integration of remotely sensed data with other georeferenced data systems. The proceedings clearly reflect the trends to integrate remotely sensed data with a number of different georeferenced data systems and illustrate an emerging interest among a number of different specialties for use of these integrated data systems in environmental assessment and resource management.

There also appears to be a strong interest in developing countries for the acquisition and utilization of low to moderate cost hardware and software. It is the opinion of the editors that this symposium brought together a mix of professionals--the providers of hardware and software and the users--that needed to communicate with one another. The conference provided the proper setting for an exchange of information which will serve to improve the understanding of all the needs in this emerging field.

June 1988

Dr. Robert T. Aangeenbrug, Co-Editor
Yale M. Schiffman, Co-Editor

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AAG would also like to acknowledge the Program Advisory Committee for their assistance in developing the sessions. This committee consisted of Ray Allison (USDA), Lorraine Amico (National Governors' Association), Bob Barker (SPOT Image Corporation), Frank Baxter (ACSM) Hugh Bloemer (Ohio University), Walter Boge (ASPRS), Fred Broome (Bureau of the Census), Nicholas Chrisman (University of Washington), Jerry Dobson (Martin Marietta), Ken Dueker (Portland State University), Michelle Ellrod (Marine Technology Society), Earl Epstein (NOAA), Sheila Frye (NOAA), Tom Gilding (National Agricultural Chemicals Association), Barry Glick (Spatial Data Sciences Inc.), Michael Goodchild (University of Western Ontario), Lars Greczy (U.S. Army Engineer Topographic Laboratories), Mason Hewitt (EPA), Robert Jaske (FEMA), Dennis Johnson (U.S. Forest Service), Richard Kott (EOSAT Corporation), Cliff Kottman (DMA), Millington Lockwood (NOAA/NOS), James Merchant (University of Kansas), David Moody (USGS), Richard Mroczynski (EOSAT Company), Denny Parker (Colorado State University), Liz Porter (U.S. Army Engineer Topographic Laboratories), Carl Reed (Delta Systems), Vincent Robinson (University of Calgary), Rolf Schmitt (U.S. Department of Transportation), Duane Sonnenburg (BLM), Theodore Steinke (University of South Carolina), Henry Tom (National Bureau of Standards), William Ubbens (USDA), Tom Usselman (National Research Council), and Fred Wood (Office of Technological Assessment).

AAG thanks those members of both committees who devoted their time and energy to the review and final selection of papers that were presented at the symposium.

AAG also acknowledges the sponsors--the National Aeronautics and Space Administration, the Bureau of Land Management, the U.S.

Army Engineer Topographic Laboratories, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey--who provided in-kind services, financial support, and contributed to the technical substance of the program.

Finally, special appreciation goes to the National Aeronautics and Space Administration which is making the publication of these proceedings possible.

June 1988

Dr. Robert T. Aangeenbrug, Co-Editor
Yale M. Schiffman, Co-Editor

DATA BASE MANAGEMENT: CARTOGRAPHY

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TRIANGULATED DATA STRUCTURES FOR MAP MERGING AND OTHER APPLICATIONS IN GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

The partitioning of a single space or map region into triangles or triangular regions has proved to be very useful in numerous diverse applications of geographic information systems. Triangulated irregular networks (TINs) have been successfully used in applications in elevation modeling and representation, in network analysis and routing problems, in land use and hydrologic studies, in roadway design and landscape visualization, in nearest-neighbor search and zoning problems, and in many other searching, sorting, and spatial data organization problems.

This paper examines some of the key properties of triangulations in general, the Delaunay triangulation in particular, and especially focuses on those properties which permit easy manipulation and comparison of two data sets that have been organized into similarly triangulated data structures. Tools for "navigating through" triangulated data sets and for decomposing the triangles or for building additional structures upon the triangles are shown to behave well under transformations of data sets. These transformations include joint triangulations, the *simultaneous* decomposition of *two* spaces into triangular regions, which has the potential for providing additional TIN applications in the two-space case.

The growing need to overlay two maps (of near-identical or different coverages) and to match or compare point features on those two maps will make joint triangulation techniques more important and more useful every day. Compatible TIN coverages on both spaces permit straightforward comparisons between the spaces and provide a sound mathematical foundation for those comparisons.

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1. INTRODUCTION

The triangulation of a planar domain—partitioning it into a finite family of triangular regions—provides a key tool for automating the interplay among (1) finite sets, (2) finite combinatorial topology, and (3) two-dimensional, infinite-set, continuous geometry/topology. A triangulation starts with a finite set of points (which will become triangle vertices), then builds a finite collection of line segments or triangle edges (recorded as point pairs), another finite collection of triangles (recorded or stored as point triples), and finite collections (implicit or recorded explicitly) of triangle adjacency relations and triangle edge inclusion relations. The triangulation begins and ends with finite sets; however, the resulting finite collection of triangles, edges, and vertices account for all of the infinitely many points of the continuous two-space that has been triangulated. A triangulation partitions* infinitely many points of space into finitely many managable sets of points, edges, and triangles, each of which requires only fixed storage to describe completely. These finitely many sets are all well behaved, well studied, and well understood, and their topological and geometric structure lends itself nicely to computerization.

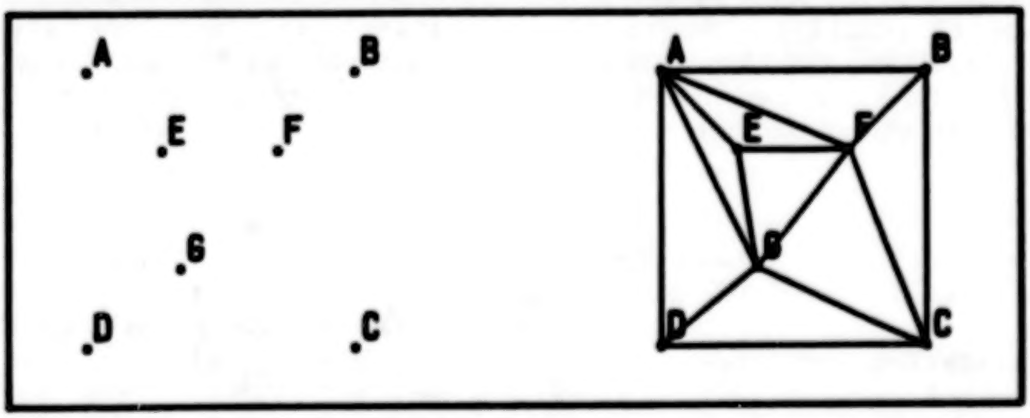

Figure 1. A set of points and a triangulation of those points

The resulting lists used for recording the triangulation are:

Points:
(A, B, C, D, E, F, G)
Segments:
(AB, AD, AE, AF, AG, BC, BF, CD, CF, CG, DG, EF, EG, FG)
Triangles:
(ABF, ADG, AEF, AEG, BCF, CDG, CFG, EFG)

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*In order to form a partition in the strict mathematical sense, edges do not contain their end points and triangles are open (i.e. they do not include their boundary edges or their vertices).

2. GENERAL TRIANGULATION CONSIDERATIONS

Obtaining a triangulation may be a goal in itself (in order to partition all of space in some useful fashion) or it may be an intermediate goal (as in generating an elevation model). There are many possible triangulations for most point sets. (Just counting all of the possible triangulations for an arbitrary point set is a very hard open problem which has been solved in only a few special cases. Even the "easy" cases, such as "n points are vertices of a convex polygon" have complex solutions.)

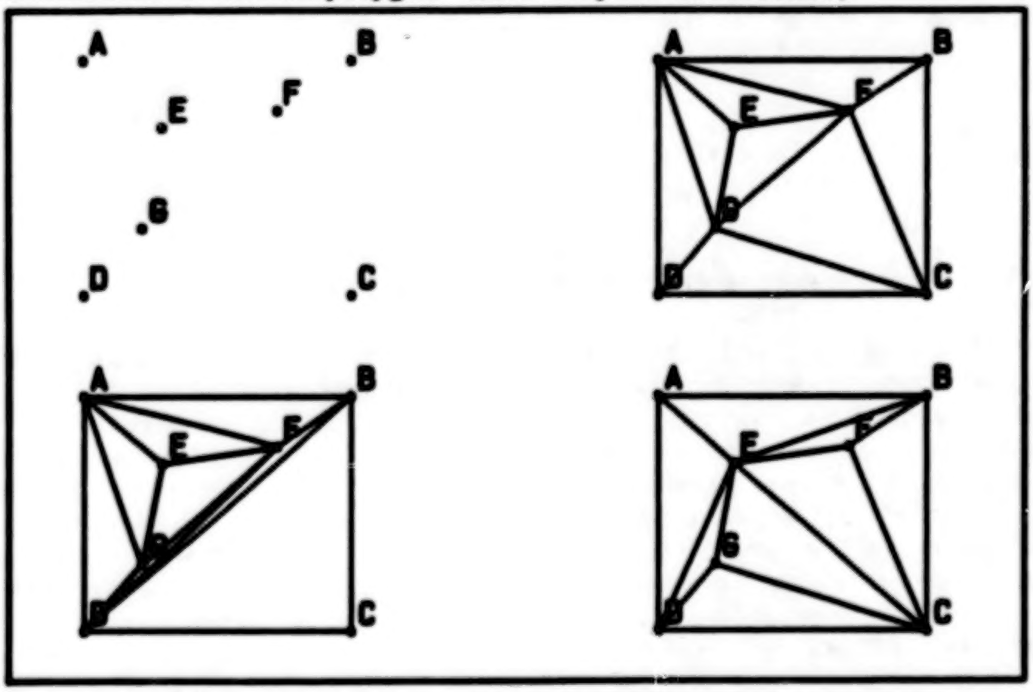

Figure 2. A finite set of points and three distinct triangulations

Some triangulations, such as the Delaunay triangulation (upper right in Figure 2), are more suited for certain applications. Most useful triangulations, including the Delaunay triangulation, can be built in $O(n\log n)$ worst-case time, where n is the number of points on which to triangulate. With appropriate data structures, triangulations can be searched and updated quickly (often in $O(\log n)$ expected time). This paper describes some of those structures. A *triangulated data structure* will refer to any abstract data structure specifically organized to facilitate representing and accessing the elements of one or more triangulations and their topological and geometric relations. Some examples of triangulated data structures are Chris Gold's binary adjacency trees [3], David Kirkpatrick's triangulation refinement digraphs [4], and adjacency pointer structures such as DIME or "winged edge" and TIGER, with possible enhancements to exploit special facts such as: every triangle has exactly three vertices and exactly three triangle neighbors.

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Before looking at specific triangulations and some useful data structures in detail, this paper focuses on a specific application of triangulations that will be generalized later. Suppose that a triangulation is given and fixed for the moment. Membership of any point in space in any triangle is well-defined—the point is either in the triangle or not in the triangle—and easily checked. Furthermore, if the point is in the triangle, its position in the triangle with respect to the three vertices can also be precisely defined. This well-defined position permits functions to be extended over an entire triangle when the functions are only defined at the three vertices. Furthermore this extension by triangles agrees on triangle overlap, and thus gives an extension to the whole space. The ability of a triangulation to extend point functions to all of space is a very useful property.

3. FUNCTION EXTENSION PROPERTIES OF TRIANGULATIONS

Elevation models and their classic utilization of triangulation methods typify the function-extension property of triangulation applications: elevations are measured at discrete sites in order to estimate elevations everywhere on a surface. Estimation at all non-measured sites is accomplished by averaging measured values at "nearby" sites; and the triangulation effectively determines (1) which sites are "nearby" and (2) how those "nearby" sites should be weighted to produce the desired average. The triangle to which a non-measured site belongs assigns it three neighboring vertices of "nearby" sites; the relative nearness to each of those sites determines the weight that each vertex elevation should be given. A rule of linear interpolation is easiest to describe and to illustrate: Suppose that the point q belongs to the triangle determined by p_1, p_2, and p_3. Then q can be expressed <u>uniquely</u> as:

$$q = a_1p_1 + a_2p_2 + a_3p_3$$

where $a_1 + a_2 + a_3 = 1$; and a_1, a_2, and a_3 are all non-negative. The unique a_1, a_2, and a_3 are called the convex coordinates of q.

If each p_i has associated elevation e_i, for $i = 1, 2, 3$, then the elevation at q (call it e_q) is given by:

$$e_q = a_1e_1 + a_2e_2 + a_3e_3, \text{ for the same } a_1, a_2, \text{ and } a_3$$

This interpolation computation gives consistent results on shared triangle edges. It also works for vector-valued functions, not just scalar functions such as elevation. In particular, vector-valued functions are interpolated to produce a special class of transformations called triangulation maps [7] and rubber-sheeting transformations [10] of the plane for map conflation [8].

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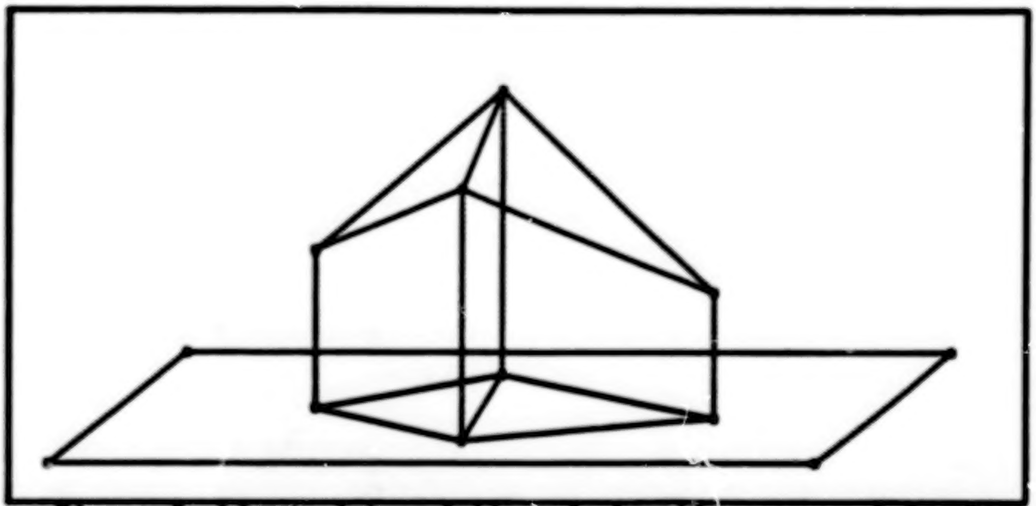

Figure 3. Linear interpolation of elevation over a triangle

4. DESIRABLE PROPERTIES OF DELAUNAY TRIANGULATIONS

Many triangulation packages in operation in geographic information systems, in computer-aided engineering, and elsewhere build Delaunay triangulations rather than some other type of triangulation. This section reviews some of the important properties of the Delaunay triangulation that make it most suitable for numerous applications (see also [6]).

1. A Delaunay triangulation on a set of points is a triangulation such that the circumcircle of any triangle (the circle passing through the three triangle vertices) contains no point of the set in its interior. This circle property fully determines a Delaunay triangulation. A Delaunay triangulation always exists.

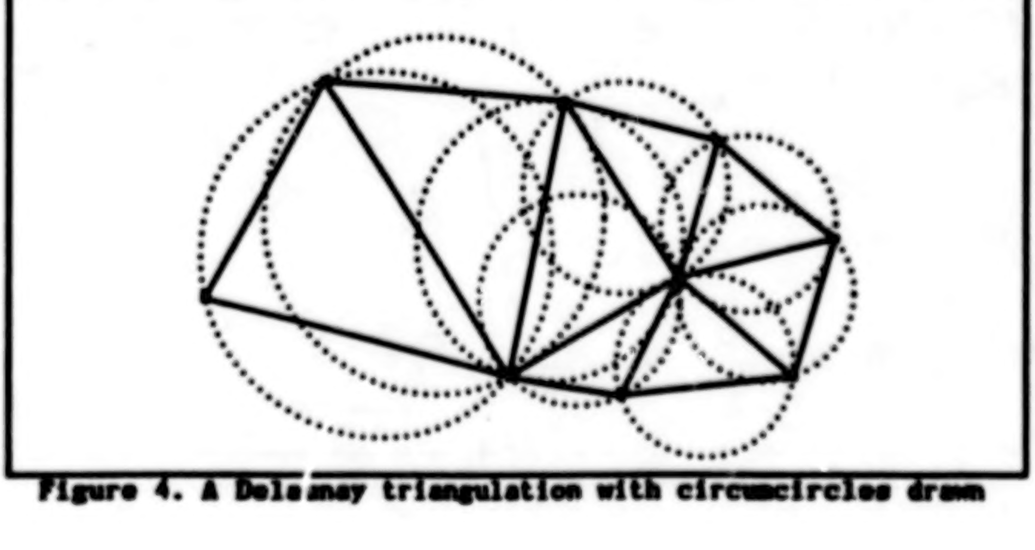

Figure 4. A Delaunay triangulation with circumcircles drawn

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2. If no four points of the set are co-circular (i. e. lie on the same circle), then the Delaunay triangulation is unique. A Delaunay triangulation is always unique up to diagonal swapping within polygons whose vertices are co-circular.

3. Furthermore, if no four points are co-circular, then an edge will belong to the (unique) Delaunay triangulation if and only if there exists a disk containing both endpoints of the edge and no other point of the vertex set.

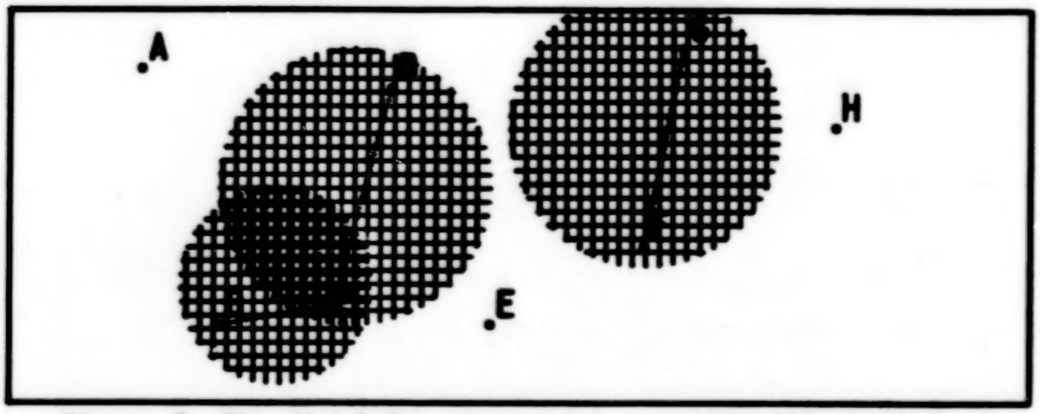

Figure 5. The disk/edge separation property illustrated

4. Because the circle property (1) and disk property (3) fully determine the Delaunay triangulation, the Delaunay triangulation of a point set will remain invariant under any transformation of the point set that preserves circles and circle containment. Rigid motions, scalings, reflections, and combinations of the three movements all preserve circles and circle containment.

5. The Delaunay triangulation is the planar graph dual to the Voronoi diagram which delimits planar regions according to their nearest point in the vertex set. The Voronoi dual is a useful structure for nearest neighbor searches; and it may be obtained from the Delaunay triangulation in $O(n)$ time and vice versa.

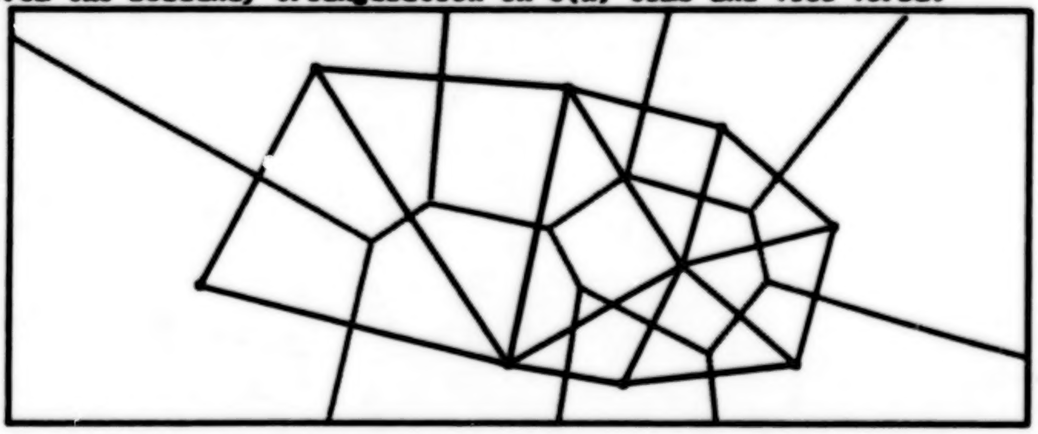

Figure 6. A Delaunay triangulation and its Voronoi dual

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6. The Delaunay triangulation maximizes the minimum angle of all the angles that are present in the triangulation. This property is useful if very small angles can cause problems, as in the distortion resulting from piecwise linear homeomorphism of narrow triangles. Although the Delaunay triangulation does not minimize the maximum angle, it does tend to eliminate very large angles simply by enforcing the supplementary relation of three angles of a triangle, namely, they must add to 180 degrees; and if the smaller angles are not too small, then the largest angle cannot be too large. There are applications such as finite element analysis which seek to avoid large angles; and for these applications, the Delaunay triangulation gives good results.

7. The Delaunay triangulation (when unique) produces the lexicographically largest increasing sequence of angles possible in any triangulation. This means that if the angles of the Delaunay triangulation are listed in non-decreasing order:

$$\alpha_1 \leq \alpha_2 \leq \ldots \leq \alpha_i \leq \ldots$$

and if any other triangulation has its angles ordered similarly:

$$\alpha_1 \leq \alpha_2 \leq \ldots \leq \beta_i \leq \ldots$$

where α_i and β_i are the first term for which the sequences differ,

$$\text{then } \alpha_i > \beta_i.$$

This property is a generalization of property (5). It may also be used to extend the definition of Delaunay triangulation to specify further the case of four or more co-circular points.

8. A Delaunay triangulation may be updated locally with addition or deletion of vertices. The local update affects only triangles whose circumcircles contain the update point. An update can be accomplished with an incremental algorithm that adds a vertex in $O(\log n)$ average-case time and removes a vertex in $O(1)$ (constant) expected time when (1) vertices are in general position and (2) appropriate topological linkages are efficiently encoded in the data structure.

9. A $\Theta(n\log n)$ worst-case divide-and-conquer algorithm exists for building the Delaunay triangulation. The $n\log n$ factor arises from sorting the data, which seems to be a necessary pre-processing step for any triangulation, and especially for the Delaunay triangulation which depends entirely on local behavior of vertices. After pre-processing the vertices to group them locally, the Delaunay triangulation may be found in expected linear $O(n)$ time.

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5. STRUCTURES FOR BUILDING AND NAVIGATING TRIANGULATIONS

Christopher Gold once remarked in a talk on triangulations that topological structure is too valuable to throw away. The Bureau of the Census has always affirmed the preeminence of topology as well for its general cell-based map model. The TIN programs developed by Environmental Systems Research Institute generate their triangulations as topological structures, complete with information about adjacency among the nodes, the edges and the triangles themselves. An awareness of the advantages of making topology a part of the triangulated data structure has made advocates of many users. A triangulation has topology; and the prevailing philosophy is to store that topology in an explicit, accessible format along with other triangulation information. As an example of an alternative approach, a triangulation may consist of something as minimal as an edge list—where verifying the fact that the edges actually constitute a triangulation or determining which edges belong to which triangles are left to the user. While topology is clearly constructible at a cost, many of the newly developed applications of triangulations, such as flow analysis, require ready network construction and traversal; and these can only be accomplished efficiently with full topological linkages.

Topology of triangles is somewhat simpler than topology of polygons, although in many ways it is the same. An n-sided polygon may have up to n distinct neighbors, each sharing an edge. A triangle may have only three. In terms of fixed-field data records, this characteristic is helpful. A triangle also has exactly three vertices and three edges, again useful from the fixed-field data record aspect. Geometry of triangles is even more constraining. A triangle is a rigid body in the sense that it is the only polygon that is fully specified by its side lengths. It is also the only polygon whose interior points can be expressed uniquely as a convex combination of its vertices. This last fact makes all ordered triangles affinely equivalent—any triangle with ordered vertices may by mapped onto any other triangle with ordered vertices by an affine map that sends the three vertices of the first triangle to the corresponding vertices of the other triangle. The affine map in question merely uses the same coefficients to form the convex combinations of vertices.

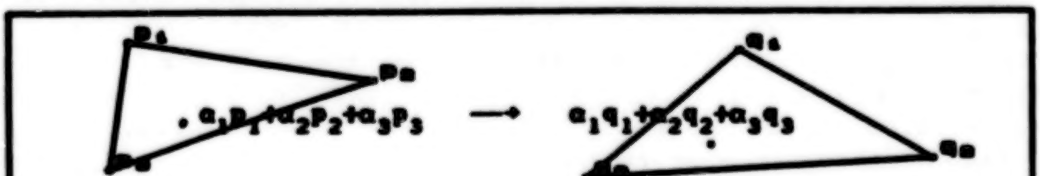

Figure 7. Affine map between triangles

The affine maps between triangles described above induce coherent maps between a triangulated space and a space with distinguished points corresponding to the vertices of the triangulated space. Such a map is called a triangulation map; and the image of the triangles may or may not triangulate the image space. A straightforward test involving preservation of triangle orientation has been devised to determine if the image space is also triangulated [7]; and if both spaces are triangulated by the corresponding triangles, then the triangulation map produces a joint triangulation. A joint triangulation is a topological homeomorphism--a one-to-one bicontinuous association of all points in one planar region with the points of another. Homeomorphic functions do not fold or tear a space when they transform it. A joint triangulation permits a finite description and storage of the homeomorphism relationship involving infinitely many points, just as an ordinary triangulation partitions infinitely many points into finitely many sets that can be manipulated by the computer.

Joint triangulations can be used to produce overlays which are aligned at arbitrarily many points [8]. The remaining points will maintain their topological relationships and produce the rubber-sheet effect desired. Non-linear rubber-sheeting, also popular for alignment tasks, is computationally more complex and may even run a risk of failing to preserve topology. In any case, verifying or proving that topology is preserved by non-linear adjustments is usually harder than doing so in the piecewise linear case. Three key results of a study of joint triangulations are stated here (for proofs see [7]):

1. A triangulation map can be tested for homeomorphism (joint triangulation) in linear time.

2. Although it is not always possible to extend a finite map from n distinct points to n distinct points to a joint triangulation of their convex hulls, it is always possible to augment the associated pairs of n points, giving a finite map of n + m distinct points to n + m distinct points (which sends the original n points to the corresponding original n points) in such a way that one can then find a joint triangulation of the augmented sets.

3. Joint triangulations exist for which one triangulation is Delaunay and the other is not. It is not always possible to find a joint triangulation which is Delaunay in either space. However, by permitting augmentation of the vertex set, one may guarantee the existence of a joint triangulation for which the first triangulation is Delaunay. It may even be possible, with augmentation, to guarantee a joint triangulation involving two Delaunay triangulations, although it is not known at this time.

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6. SOME PRACTICAL EXPERIENCES

Census Bureau researchers have found that, in their applications, the following information has proved useful for manipulating a triangulated data structure:

1. TIGER-like topology.

   A. Files of 0-cells, 1-cells, and 2-cells.
   B. 0-cells with coordinates, pointers to "first 1-cell."
   C. 1-cells pointing to "to" and "from" 0-cells, "left" and "right" 2-cells, and four other 1-cells.
   D. 2-cells (triangles) pointing to three 0-cells, three 1-cells, and three neighboring 2-cells.

For direct spatial search queries, structures with $O(\log n)$ access time are available. The Census Bureau stores Peano-key sequences in B-trees for logarithmic access.

2. Vertices in Peano-key order accessed through a B-tree.

For neighborhood searching, coefficients of the straight line equation describing an edge permit a quick test to determine on which side of the line a point lies. The test consists of plugging the point's coordinates into the line formula and computing the sign of the expression.

3. Coefficients of the line equation of each 1-cell.

For building or maintaining a Delaunay triangulation, the circumcircle centers and radii are also useful data points [9]. (For computational purposes, the square of the radius is more easily computed and is often kept in the data structure).

4. Radius (squared) and center of circumcircle, with centers in Peano-key order stored in a B-tree.

Other tree-like structures to record adjacency of triangles or history of evolution in the case of incremental construction have been mentioned in the introductory section. Depending on applications, these additional structures may be well worth the overhead to store and maintain them. For recurring search applications with limited or local update requirements for the triangulation, a triangle-based directory of data points may be an efficient search tool [8].

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TOWARD GEOMETRIC SIGNATURES FOR GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

Multi-parameter fingerprinting of terrain, from computer analysis of digital altitudes, is proposed for automating the classification and correlation of topography within a geographic information system (GIS). The key analytic tool, the geometric signature, is a set of quantitative variables that describes topographic form well enough to distinguish geomorphically disparate landscapes. In a brief example using 1:62,500-scale map data, five classes of descriptors computed automatically from digital profiles yield experimental signatures for 12 physiographic divisions. Multivariate analysis suggests that 40 variables may represent as few as eight different attributes of landscape geometry. In decreasing order of importance and certainty these are altitude dispersion, fine spacing, altitude symmetry, slope angle symmetry, texture, coarse spacing, proportion of broad- to fine-scale relief, and elevation.

1. BACKGROUND

Quantitative modeling of large areas of topography is a developing concept within geographic information systems (GIS) analysis (1). It has evolved from the long-recognized need to express topographic form in terms more exact than flat, rolling, or hilly (2, 3) and parallels advances in other fields (4). New computing technology and the mass production of digital altitude data carry the potential for breakthroughs in the characterization of land form. For example, it should be possible to simulate the visual perception of topography. This might even be done well enough to distinguish landscapes shaped by different processes. Embedding such simulations within a GIS has many applications. These include identification of natural hazards, numerical mapping of topographic and environmental units, and correlation of land-surface form with data from Landsat and other sources (1).

The approach taken here identifies some interim goals that would aid in realizing these new opportunities: 1. Represent continuous, randomly sampled, topography as an assemblage of discrete lines and nonoverlapping planes. 2. Sample and describe continuous topography without necessarily being restricted to such customary areal units as fluvial watersheds. 3. Identify the geometric constituents of land form and estimate their relative importance and degree of

interdependence. 4. Automate topographic description over large areas by computerized algorithms that require minimal human interaction. The four objectives are being pursued in experiments with image-processed digital elevation models (DEMs) in Central California (1) and with small digital matrices (5) and profiles (6) from the United States at scales of 1:24,000 to 1:1,000,000.

This paper reviews some of the above work and describes various kinds of terrain input for GIS analysis. Specifically, it discusses both topographic profiles and high-density altitude matrices as representations of land form, develops the concept of the geometric signature for abstracting topographic form parametrically, and outlines some possible constituents of a signature. A multivariate comparison of topographic profiles from 12 physiographic provinces in North America illustrates these three contributions.

2. SOME ENABLING TECHNOLOGIES

Two developments have advanced the art of landform characterization to a level once entertained only by visionaries (2, 3, 7). First is the modern computer. Large, fast machines and the attendant programs can manipulate altitude data in increasingly sophisticated ways. The most relevant improvements in computer software for landform analysis are in image processing, pattern recognition, the analysis of shape (morphometry), and GIS -- particularly the capabilities for spatial taxonomy promised by such advanced techniques as the triangulated irregular network (TIN).

The other development, mass-produced digital altitudes at medium-to-fine scale, derives from the first. About 1/3 of the 7.5' DEMs that will constitute standard coverage for the United States at 30m x-y resolution are available. Currently most of them are marred by varying accuracy and artifacts of digitizing. The latter, evident as stripes in the topography (1), are eliminated by a new (contour-scan) digitizing process. Slow production of the revised DEMs still restricts detailed or conceptually advanced studies of topography to coarser-scale altitude matrices and manually-captured samples.

3. PRECONDITIONS FOR LAND-FORM INTERPRETATION

GIS-based fingerprinting of topography from digital data will find its most enduring value in geomorphology, not just terrain quantification (2). A numerical link between topography and its underlying materials, formational processes, and history requires an unbroken string of four conditions: First, unique surface forms that result from different processes must be recognizable in the field, on photographs, or in spacecraft images. These imprints include both discrete landforms (watersheds, drumlins, landslides) and composites of related landforms, or landscapes.

Second, topographic maps must carry enough detail to show these diagnostic features. Where map resolution is as fine as the size of the smallest features of significance, maps can substitute for field observations of shape (cf. 4). Such high standards were met by the 7.5' quadrangles of New England, which led to the establishment of a morphostratigraphic sequence for Quaternary glaciofluvial deposits.

Third, digital altitudes must preserve the essential details of the original contour maps. Sampling theory dictates that evenly-spaced altitudes can represent terrain features no smaller than twice the grid spacing (the Nyquist, or folding, frequency). For example, the ability of the 7.5' DEMs to capture topography successfully requires the breadth of diagnostic features to exceed 60 m.

Fourth, measures that describe land form must abstract its key elements, those that give each landscape its essential character. Thus any suite of variables, or multivariate characterization, must be comprehensive and detailed. This condition is the principal concern of the balance of the paper, which discusses some possible ingredients of a GIS-based system for representing topography.

4. A GEOMETRIC SIGNATURE OF LAND FORM

A signature may be topologic (4), an approach not pursued further here, or parametric, "a set of measurements sufficient to identify unambiguously an object or a set of objects" (8). The latter concept, implicit in earlier work on terrain (3, 9), adapts from remote sensing to land-form analysis (10). Topography can be fingerprinted by computer manipulation of altitude data, perhaps most effectively within the analytic framework provided by a GIS. Accordingly, a geometric signature is a set of measurements that describes topographic form well enough to distinguish geomorphically disparate landscapes. The signatures discussed here are for continuous topography, or landform composites (general geomorphometry; 2, 11), not individual landforms (specific geomorphometry; 11), but the signature concept accommodates both.

Geometric signatures devised by the parametric approach consist of central-tendency and dispersion statistics of various terrain attributes (12-15). The constituents of a signature belong to quasi-independent groups of descriptors, perhaps half of which are areal (x, y) properties and half are profile, or vertical (z), attributes. About a dozen categories are now recognized: altitude, relief and slope, fine texture, altitude skewness, slope curvature in plan and profile, slope azimuth, coarse texture, alignment in plan, proportion of fine- and coarse-scale slopes, drainageway and ridgeline topology, peak frequency, and areal homogeneity (9-13).

A signature invokes four related postulates. Perception of land form in the field is aggregative, or synthetic. An observer sees

not just relief and drainage density, but rather sees and integrates a vast set of terrain attributes (3, 5, 11). This set is a collection of geometric continua, often perceived as dominant patterns (9, 12), which can be abstracted by discrete parameters to form signatures. Next, topographic character is scale dependent; terrain attributes and their interrelations are not self-similar at all levels of generalization (2, 6, 10, 16). Third, if parametric, the representation of terrain from digital data is multivariate. No one magic number can express land-form character completely enough to fingerprint topography or interpret morphology (2, 3, 11). Lastly, the abstraction of terrain is a statistical problem; its implementation requires a statistical approach (11, 13, 14).

No specifications exist for a correct signature. Minimally, it need only distinguish among a wide range of different, but similarly sampled, topographic surfaces. Elementary signatures can solve general problems. E. H. Hammond compiled his continental-scale map of land-form classes from a signature of just slope, relief, and hypsometry (12). Six parameters were enough to derive physiographic provinces for Central Europe (3). A more inclusive signature (e.g., 5) would be required to discriminate such geometrically similar, but genetically different, landforms as end moraine, sand dunes, and mature karst, or to recognize the representative plan-profiles of (9). More fully realized, a geometric signature might largely reconstruct the original source topography; this would require the aid of other, commensurately sophisticated, methods (4).

Variables for a geometric signature are obtained from specialized computer programs (7, 11), which may be incorporated into image-processing or GIS packages for improved ease of manipulation. The software used here was designed earlier, for the characterization of the Moon's terrain (15). It computes statistics of topographic attributes from either profile (6, 10) or matrix (5) samples. The profile version calculates about 50 separate variables for traverses oriented in one of four directions along x, y, or diagonal directions in a DEM window or sample space (Table 2; details in 15).

5. PARAMETERS FOR A SIGNATURE

Five groups of descriptors, mostly in the z domain (fig. 1), are discussed below and then used in an example. Although these groups emphasize surface roughness at the expense of other attributes, they are sufficient for many applications (5, 10, 11, 13, 15).

Altitude describes general properties of topography (2, 3, 10, 12), by the standard statistics of any frequency distribution: mean, mode, median, range (relief), standard deviation, variance, skewness, and kurtosis. Topographic grain, a measure of coarse-scale texture, combines altitude with distance. Defined as size of a (nested) sample area (here, a profile) beyond which altitude range

ceases to increase significantly with area (3), grain can estimate the optimal size of a window within which to capture other data.

The __variance spectrum__ (AVS) analyzes altitude in detail along a linear or random-walk profile (10). Its estimates of the range in altitude over different wavelengths of topography are combined into log-log functions. Parameters of these plots include variance, both summed and at specific slope lengths, spacing and estimated size of terrain periodicities, and spectrum slope. The latter describes the relative proportion of roughness at different scales (10) and thus is related to the fractal dimensionality of topography (16).

Slope, the first derivative of altitude and the single most important parameter of topographic form, is calculated in many ways (11). __Slope between topographic reversals__ (SBR) is a surface-specific variable (17) defined by adjacent hilltops and valley bottoms along a profile (15; fig. 1). Parameters of SBR calculated along DEM ranks, files, or diagonals include frequency of reversal (fine-scale texture), statistics of slope angle, length, and height, and slope of the relation between slope length and its angle.

__Slope at a constant length__ (delta-L) and its multiples supports the most popular measures of topography (11; fig. 1). Variables are calculated along DEM profiles for both unsigned (absolute values) and signed slopes (those facing the start of a sample traverse are designated positive). All the usual statistics apply to the signed distributions, which are symmetric about zero slope and commonly approach the Gaussian ideal. Unsigned distributions are skewed. Variables recomputed at several base lengths yield curvilinear relations that describe the scale-dependence of slope (6).

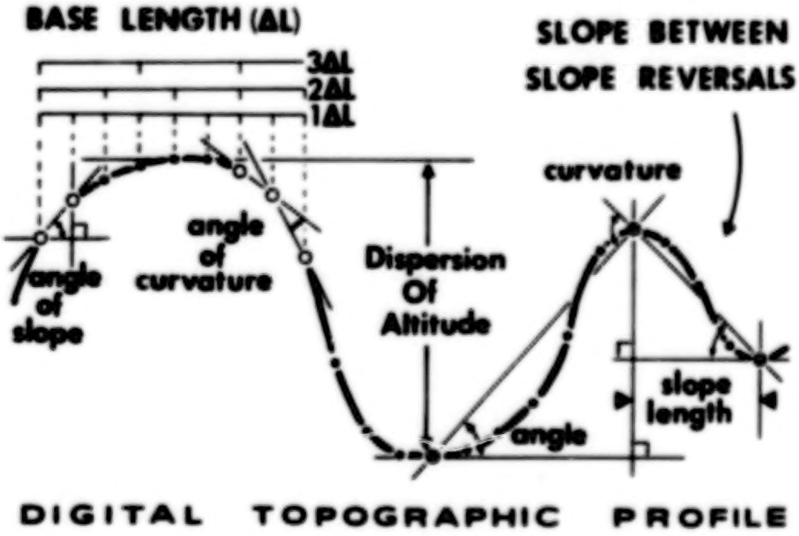

Figure 1. Some topographic descriptors defined diagrammatically.

Curvature in profile, the second derivative of altitude, measures relative steepness, or slope relative to slope (i.e., independent of the horizontal datum) (11). Most properties of base-length slope apply to curvature at constant length, the fifth category of topographic attributes (5). Curvature is the supplement of the angle subtended by three adjacent elevations along a digital profile (fig. 1). The signed convention for slope is carried over so that convex-upward curvatures are positive, and concave values are negative. Calculations of curvature between reversals, analogous to SBR and thus a sixth category, were not available for this paper.

6. SIGNATURES OF LAND-FORM TYPES FROM DIGITAL DATA

An example illustrates the above ideas by adapting digital-terrain methods to an old problem in physical geography, distinguishing among broad-scale topographic types (2, 3, 9). It also describes progress on an operational problem, choosing the composition of a signature. This pilot study is one contribution of a program to encourage the use of GIS analysis within the U.S. Geological Survey, whose long-term goals include an automated capability for evaluating and classifying vast amounts of topography from DEMs (1, 18).

The content of a geometric signature can be determined variously from a priori judgment, statistical criteria, the nature of the specific problem, or a combination of the three. The small-sample statistical approach taken here is an illustration of the method rather than an attempt at definitive signatures. I have chosen 12 topographic samples, calculated a diverse suite of 40 geometric variables for each area, and examined the 12 x 40 matrix by multivariate methods (19) A geometric signature for each sample may be chosen from either a set of statistics, the principal-component scores, or from values of variables indicated by the analysis (5).

6.1 A Topographic Sample

Data were gathered on 12 physiographic provinces in the continental U.S., mostly from maps in the USGS 100 Set and other standard sources (Table 1). These divisions remain the best classification of broad-scale topography within the U.S. (7, 17); their boundaries are not controversial. The provinces are not homogeneous, however, but contain various classes of land-surface form (12), nine of which are sampled here (Table 1). Five D6 terrains were included to examine the uniformity of the High Mountains class, and two samples each intentionally include different Hammond classes (12). The wide ranges of calculated variables (not shown) indicate that the samples roughly span the continent's topographic diversity (6, 12, 17).

In the absence of reliable DEMs, measurements for each sample were captured from a 35-km-long NW-SE traverse on a 1:62,500 topographic

Table 1. A Topographic Sample From 1:62,500-scale Maps

USGS MAP SHEET	PHYSIOGRAPHIC PROVINCE	LAND SURFACE-FORM CLASS (After E.H. Hammond; 12)	
Mt. Whitney, CA	Cascade-Sierra	D6	High Mountains
Bendeleben C4, AK	Seward Peninsula	C4b	Open High Hills
Nabesna B6, AK	Wrangel Mts.	D6,B2b	Mts, Irreg. Plain
Mt. Katmai C1, AK	Aleutian Range	D6	High Mountains
Alma, WI-MN	Wisc. Driftless	C3b	Open Hills
Sun Prairie, WI	East. Lake Section	B2b	Irreg. Plains
Elizabethtown, NY	Adirondacks	C5a	Open Low Mts.
Renovo West, PA	Allegheny Mts.	D5	Low Mountains
Promontory Butte, AZ	Colo. Plateau Rim	C5c,B5c	Mts., Tableland
Peaks Of Otter, VA	Piedmont-Blue Ridge	B4a	Plain, High Hills
Wolf Creek Pass, CO	Navajo Section	D6	High Mountains
Point Sur, CA	Cal. Coast Ranges	D6	High Mountains

map. About 210 to 235 altitudes per profile at the rather coarse spacing of 0.16 km were read manually to the nearest 0.3m to 3m, depending on slope. I did not sample the topography at finer spacings because physiographic types distinguishable by numerical criteria at moderate to coarse resolution are not necessarily identifed from small samples at fine resolution. This limitation arises from the scale-dependence of topographic character (2, 6).

Forty variables describe the 12 profiles (Table 2). Most of them are central tendency and dispersion statistics of altitude (n= 9 variables), the variance spectrum (n= 4), slope between reversals (n= 7), and slope (n= 9) and slope curvature (n= 11) at the 0.16 km sampling interval. For fuller descriptions see (3, 10, & 15). I chose the many variables to illustrate similarities and differences among the descriptors in the same and in different categories.

6.2 Multivariate Analysis

Many of the variables in Table 2 are redundant (13, 5). Analysis begins by cross-correlating all 40 variables (19; not shown). Distribution of the number of statistically significant (221 out of 780 $r \geq 0.58$) correlations with each variable is strongly bimodal. One cluster of correlations includes 18 independent variables (≤ 6 correlations each), most of them in altitude and SBR groups. The other has 19 closely related variables (≥ 14 correlations each), most of which are in the spectrum, slope, and curvature groups.

A principal components analysis (PCA) based on the 780 correlations (Table 2) reveals that altitude dispersion, or terrain steepness, is the dominant attribute in the data. PCA reduces the 40 variables to

Table 2. Scores (x100) of 40 Variables on Eight Principal Components

	VARIABLE	PC 1	2	3	4	5	6	7	8
ALTITUDE	Range (relief)	89	38	2	-12	22	1	-3	1
	Mean (see ref. 2)	67	2	26	-16	-7	47	-4	38
	Variance	64	53	15	-24	43	-1	6	13
	Std. Dev.	77	41	11	-15	45	-2	-1	8
	Skewness	-2	49	-75	-20	-21	-21	-15	15
	Kurtosis	18	16	-80	1	-29	7	-42	1
	Elev./Relief Ratio (2)	10	-57	63	34	16	26	8	-15
	Topographic Grain (2)	40	32	-13	-8	-36	69	13	-13
	Rel. Relief @ Grain (2)	90	37	2	-13	17	7	0	-3
SPECTRUM	Variance @ 3 km Length	75	43	20	-18	37	-3	-1	15
	Variance @ 1 km Length	92	-16	4	14	-22	-20	11	10
	Variance @ 0.33 km	93	-2	8	7	-4	-28	15	1
	Slope: Spectrum Eqn.	-22	-62	-7	-11	-39	-16	50	-9
SBR	Slope Reversals/km (2)	-16	-61	-58	-20	35	23	14	5
	Length 3rd Steepest	19	90	-15	-2	-5	5	30	-11
	Angle 3rd Steepest	92	-27	-22	9	-6	-1	9	0
	Length 3rd Longest	25	85	12	-20	-19	-3	31	-6
	Angle 3rd Longest	88	0	16	17	-5	-25	-27	-4
	Slope: Angle/Length Eqn	-33	54	8	74	-10	6	3	4
	Median SLope length	22	11	85	37	4	-13	-13	-6
AL SLOPE	Signed Std. Dev.	97	-14	-9	12	-10	-3	4	-5
	Signed Skewness	-31	56	-2	66	-27	8	4	24
	Signed Kurtosis	-65	46	9	49	-22	1	13	20
	Unsigned Mean (2)	95	-21	-5	17	-10	-8	4	1
	Unsigned Median	95	2	-17	13	7	17	-8	-1
	Unsigned 20th %	88	-8	-21	20	23	21	-1	2
	Unsigned 90th %	94	25	14	-13	-1	-12	1	1
	Slope: Freq. Eqn.	-60	-11	32	-55	-27	-24	5	23
	Slope: Delta-L/Mean Eqn	-90	25	10	-18	24	7	-7	5
AL CURVATURE	Signed Std. Dev.	91	-28	-17	16	-12	-3	8	8
	Signed Skewness	37	65	8	-53	-18	-13	1	-25
	Signed Kurtosis	-28	86	-11	23	-12	-14	11	-12
	Unsigned Mean	88	-35	-14	19	-11	-5	6	14
	Unsigned Median	94	-3	-19	5	10	20	-7	-1
	Unsigned 20th %	94	-11	-17	11	16	1	11	-4
	Unsigned 90th %	96	-2	-5	1	11	-1	14	1
	Slope: Freq. Eqn.	-73	-8	35	-41	-25	-17	10	24
	No. Concave/No. Convex	56	-4	33	-41	-50	22	8	4
	No. Reversals/km	-29	-4	-47	19	62	-7	48	10
	Slope: Delta-L/Mean Eqn	-87	36	14	-20	19	8	-6	-5
Percentage of Total Variance		43	19	11	9	7	4	3	2

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Table 3. Eight Dominant Attributes of 12 x 40 Topographic Matrix

PC No.	HIGHEST-SCORING VARIABLE		INTERPRETATION: Attribute Of Topographic Geometry	RELATIVE IMPORTANCE
	Category	Statistic		
1	AL Slope	Signed Std. Dev.	Altitude Dispersion	43 †
2	SBR	Length Steepest	Fine Spacing	19
3	Altitude	Kurtosis	Altitude Symmetry	11
4	SBR	Length/Angle Eqn.	Slope Angle Symmetry	9
5	AL Curv.	Reversal Freq.	Texture?	7
6	Altitude	Topo. Grain	Coarse Spacing	4
7	Spectrum	Eqn. Slope	Coarse Slope/Fine Slope	3
8	Altitude	Mean	Alt. Central Tendency	2

† Variance accounted for by each principal component (PC) in Table 2

11 uncorrelated components, or synthetic variables, extracting the strongest (PC1) first (19). The numbers in Table 2 are statistical scores (correlations) of each <u>component</u> with each <u>variable</u>. Most of the high scores are between PC1 and the many variables, mostly of spectrum, slope, and curvature, that compose it. Thus PC1 accounts for the greatest variance (43%) within the original 12 x 40 matrix

PCs 1-8 are interpreted as independent attributes of topography from which a geometric signature can be extracted. Table 3 summarizes this model in terms of the high-scoring variables on each component, their category, relative importance, and the chief attribute of terrain represented by the component. The latter choices can be subjective because ambiguities arise from scores split among several components and from weakness of the minor PCs (5, 19). Altitude dispersion, fine texture, and altitude symmetry account for nearly 3/4 of the variance in the data, however, and thus are among the most important geometric properties of continuous topography (cf. 3, 5, 13). Altitude and SBR categories claim five of the eight terrain attributes; slope, curvature, and the spectrum account for one each.

6.3 Resulting Signatures

Table 4 gives provisional geometric signatures for 12 physiographic provinces. The four numbers in each signature are a second set of scores (x 100), correlations of each <u>sample</u> with each component (just the first four PCs are shown). Scores are weighted by the total variance per component (Table 2). As composites of several variables, PC scores are more robust signatures than values of single variables. However, the dominant variables indicated by PCA are effective signatures without the added complication of having to incorporate multivariate statistics into a GIS coverage. More

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Table 4. Geometric Signatures: Weighted Principal-Component Scores

TOPOGRAPHIC SAMPLE	LAND-FORM CLASS	GEOMETRIC ATTRIBUTE [& RELATIVE IMPORTANCE] PC1: Altitude Dispersion [43]	PC2: Fine Spacing [19]	PC3: Altitude Symmetry [11]	PC4: Slope Symmetry [9]
Cascade-Sierra	D6	43	5	5	5
Cal. Coast Range	D6	42	1	10	6
Navajo Section	D6	38	7	2	9
Wrangel Mts.	D6,B2b	31	19	4	2
Aleutian Range	D6	27	7	4	7
Allegheny Mts.	D5	22	3	7	6
Col. Plateau Rim	C5c,B5c	20	5	4	4
Adirondacks	C5a	20	6	5	6
Piedmont/ Blue Ridge	B4a	14	7	11	0
Wisc. Driftless	C3b	11	0	5	4
East. Lake Sect.	B2b	1	4	0	3
Seward Peninsula	C4b	0	12	9	9

elaborate analysis, for example by cluster techniques (19), probably is not warranted for the small data set used in this demonstration.

The 12 signatures, arrayed by PC1 scores in Table 4, all differ. Four indicated groups of samples reflect roughness, the dominant terrain attribute and the bias of the original variables. Some implied similarities among signatures are artificial: Those for the Adirondacks and the Colorado Plateau Rim, quite disparate provinces, demonstrate the consequence of mixing different classes (C5c and B5c) in one sample, rather than any lack of complementary variables needed for a more balanced or diagnostic signature. The high score of the Wrangel Mountains on PC2 also may reflect inclusion of two contrasting terrain classes, D6 and B2b. Conversely, different non-PC1 scores for the D6 samples suggest some otherwise concealed diversity among five similarly-classified mountain terrains. Further interpretation lies beyond the scope of this experiment.

7. CONCLUSIONS

A pilot study of medium-scale terrains in North America suggests that topographic samples reflecting different processes and

materials can be associated with different geometric signatures. Improved and more diverse topographic measures, which are well within the capabilities of current theory and technology, will yield more robust signatures for automated comparisons of topography.

Geometric signatures of the sort outlined here can be incorporated into a GIS. This is done by first computing values of selected topographic variables for closely spaced sample areas, or windows (e.g., 1, 11, 18), and inserting the results into a database as thematic map layers. Next, samples with different signatures are classified as, or assigned to, different topographic types. Finally, contiguous samples with similar signatures are grouped into regions of similar topography (e.g., 3, 12). These computations can be automated in raster format, from large DEMs, and the resulting maps converted to the vector format preferred for GIS coverages.

Mass-produced altitudes and the computerized techniques to manipulate them present an unparalled opportunity to incorporate within GIS a numerical expression of land form that is much more useful than altitude alone. The signature approach to quantifying topography from digital altitudes is one way to do this. Geometric signatures embedded in a GIS are useful for problems in landscape taxonomy, and ultimately can be adapted to general spatial analysis.

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DEVELOPMENT OF A DIGITAL DATA PRODUCT IMPORT/EXPORT CAPABILITY FOR A FEDERAL GOVERNMENT GIS

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ABSTRACT

Digital cartographic data products for land-use and tactical applications are becoming increasingly available. The U.S. Army Engineer Topographic Laboratories (USAETL) has on-going programs to support the evaluation of digital cartographic data from the Defense Mapping Agency (DMA). One of the interim standards that has been developed by DMA is the Standard Linear Format (SLF) for vector data. DBA Systems, Inc., under contract to USAETL has implemented a SLF throughput utility to interface with the Analytical Mapping System (AMS). The interface to SLF is described and some concerns for implementing a new standard within the constraints of existing, public domain GIS software are addressed.

INTRODUCTION

The SLF Throughput System was designed as an enhancement to the Terrain Analysis Work Station/Geographic Information System (TAWS/GIS) at the U.S. Army Engineer Topographic Laboratories (USAETL) at Fort Belvoir, Virginia. The TAWS/GIS operates a version of the AMS/MOSS/MAPS software that was originally developed under government contract for the U.S Fish and Wildlife Service, and includes modifications subsequently developed under contract to USAETL.

The purpose of the enhancement is to provide an interface to the TAWS/GIS to accept Standard Linear Format (SLF) digital data produced by the Defense Mapping Agency (DMA). The SLF Terrain Analysis data (SLF/TA) is a digital version of a Terrain Analysis hardcopy product at a 1:50,000 scale. The data is in the form of thematic overlays of various terrain features (eg., soils, vegetation, slope, transportation) for a particular coverage.

Terrain information produced at a central location may not be current or contain a sufficient level of detail required for tactical purposes. Map data must be updated according to the latest field information: new features may be added, boundaries of existing features may be changed, or existing features may be described at a level of detail not present in the source data. The SLF data structure provides the flexibility to accommodate various products at different stages in their production. There was a clear need to provide a mechanism within the existing system of the TAWS/GIS to employ this data.

Specific requirements that were met by this prototype system for throughput of the SLF data in the TAWS/GIS include:

* Transfer of the SLF/TA data from magnetic tape to the AMS subsystem of the TAWS/GIS

* Export of locally created data to an SLF tape for transfer to other installations.

* Examination of alternatives for importing and using a digital data base with multiple attributes for map features.

The SLF throughput software was developed to perform on a Hewlett-Packard 9030 computer, operating HP/UX version 5.0, at USAETL. Initial development of the system took place on a VAX 11/750, operating DEC/ULTRIX version 1.1.

SLF EXCHANGE DATA

SLF is designed by DMA to be a portable, flexible and efficient data structure for exchange of digital cartographic data via magnetic tape (DMA, 1985). It is intended to become a standard DMA product. SLF/TA data used in the TAWS program is produced on the Terrain Analysis Production System (TAPS) at DMA and conforms to FIPS/ANSI standards with all data in ASCII characters. This data is a digital version of the DMA TA hardcopy products at a 1:50,000 scale. A SLF data file will normally correspond to a map sheet overlay describing a type of terrain feature (eg. surface materials, vegetation, slope or drainage). It is a vector data structure that describes the point, line or aerial feature components of the original map plus the attribute information for the features. The format of the SLF data, the physical tape blocks, and the logical record fields are documented in DMA, 1986.

SLF maintains DSI, SEG and FEA records. The DSI, or Data Set Information, contains the header parameters, history and specifications of the data file. The SEG record contains the segment and coordinate data, and the FEA records contain the attribute description of the map features. Integral to SLF is the "chain-node" structure which requires that a segment chain be stored only once regardless of the number of features which it bounds. This eliminates double storage of common boundaries. SLF stores the segments and provides linkages to the features. The linkages allows the feature to be reconstructed from its component segments. Figure 1 illustrates the cross-referencing between features and segments.

A variable length feature header record is provided for product specific descriptive information at the feature level. The overall format is defined by SLF but the length and contents of the feature description are defined in product specific appendices. Figure 2 shows an example of a Feature Description format for surface drainage features.

OVERVIEW OF THE IMPORT PROCESS

A requirement of the SLF throughput specifies the capability of making modifications to the source SLF data. For this reason the Analytical Mapping System (AMS) was chosen as the GIS subsystem to receive the SLF data. AMS is the data input and editing component of the TAWS/GIS. AMS was designed to create a database locally through manual digitalizing of hard copy maps, or

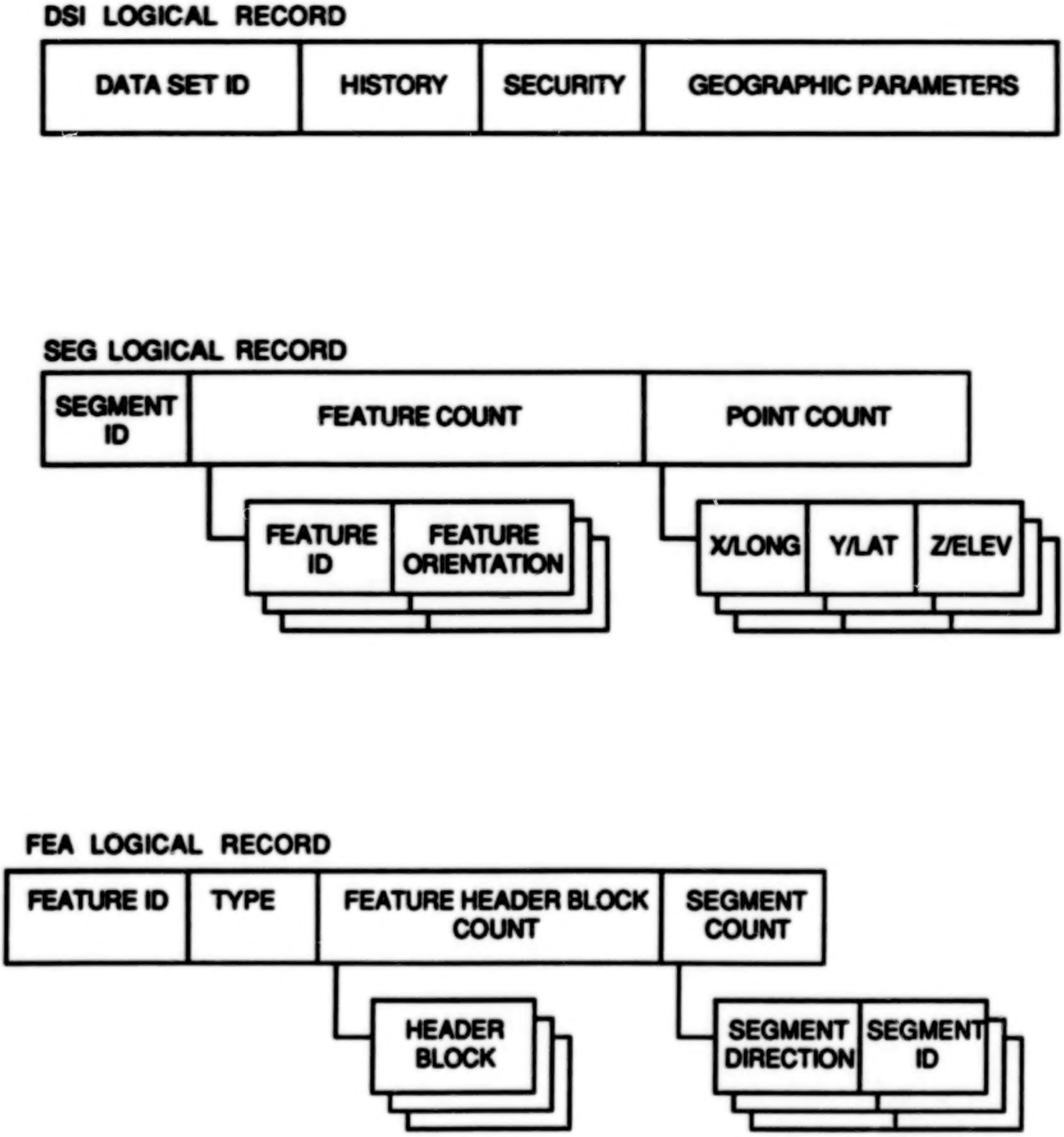

Figure 1. A schematic of SLF logical record structures. TheSegment ID and Feature ID are pointers that link the SEG and FEA record types.

through an analytical stereo-plotter or light table mensuration system for input of aerial photo source data. The Map Overlay Statistical System (MOSS), which is the analysis and overlay component of the GIS, does have an existing format to receive external data (via the ADDWAMS system). However, MOSS does not allow topological modifications to the existing data base as does AMS.

The enhancement for importing digital data to AMS requires a detailed specification of internal AMS data files and knowledge of operational procedures so that the system will recognize the "foreign" data.

The system performs the following functions:

* Displays a listing of the data files on the SLF tape.

* Provides a formatted dump of a data file contents.

* Creates a Summary Report of the contents of each file.

* Performs a partitioning of the source data so that it can be imported to AMS as individual subsets of the original coverage.

* Creates valid AMS data files from the SLF topology so that data can be displayed, plotted, registered on a base map, updated/edited, verified, and databased.

* Creates an SLF tape from AMS data files.

AMS FILE STRUCTURE

AMS maintains a set of internal, random access disk files associated with an input job (Figure 3). The data structure is an "arc-node" structure that explicitly identifies all the topographical elements including segments, nodes, edge nodes, polygons, and coordinate data. Each entity type is contained in a special file. A system of file pointers exist to cross-reference all the connected elements and allows the software to maintain the integrity of the data base when topological elements are added, deleted and modified.

The "arc-node" data structure used in AMS can be created from the simple chain-node structure of SLF with some restructuring and creation of new information unique to the AMS data structures. An example of this restructuring is the creation of the AMS "Normal Node File". Nodes are important elements in an arc-node data structure. They define the junction where two or more segments come together. In SLF, nodes are not explicitly identified, but are simply the first and last points on a segment "chain". The SLF import process identifies these points as nodes and assigns linkages required by AMS to identify the segments that join at a particular node. The structure of the Normal Node File, including pointers, is maintained as nodes are added.

AMS DATA FILES

Record in the SEGMENT INDEX FILE (SIF)

• Pointers to record in the SCD file
  Left, Center, and Right feature attributes
• Pointers to POL for Left, Center, and Right features
• Pointers to NNF and ENF for beginning and ending node
  Minimum bounding rectangle of segment

Subrecord in the NORMAL NODE FILE (NNF)

  Latitude coordinate of node
  Longitude coordinate of node
  Number of segments attached to node
• List of record numbers in SIF

Record in the SEGMENT COORDINATE DATA FILE (SCD)

  Number of coordinates in this record
  Minimum bounding rectangle of this record
  List of coordinate points

Subrecord in the EDGE NODE FILE (ENF)

  Delta longitude (for an edge on the North or South edge)
  Delta latitude (for an edge on the East or West edge)
• Record number in SIF for segment attached to the edge node

Record in the POLYGON FILE (POL)

  Feature Number
  Minimum bounding rectangle of feature
  Area of feature (if polygon)
  Centroid of feature
• Type of feature (point, line polygon)
  Pointers to SIF for segments that make up this feature

RESTART FILE

  Contains job parameters for updating and displaying geounit

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Figure 3. List of Major Data Files Required by AMS and Created by the Import Process (Except POLYGON), with an Abreviated Listing of the File Contents. An Asterisk Indicates the Field is a File Pointer.

ATTRIBUTE HANDLING

SLF/TA format provides a hierarchical arrangement of descriptive information for map features (Figure 2). The SLF feature description can be of variable size, depending on the feature type and the amount of information collected. The format does not 'map' well into the AMS structure for map feature attributes. Attribute tags in AMS must be contained within a 32 character field. For practical purposes, only 18 of these characters are displayed to the user.

The interim solution adopted here is to save the SLF feature descriptions in a separate disk file during the import process. A standard feature description item, the Feature Category, or FEACAT code, is extracted for every feature in the data set and combine with the feature ID number to form the AMS attribute.

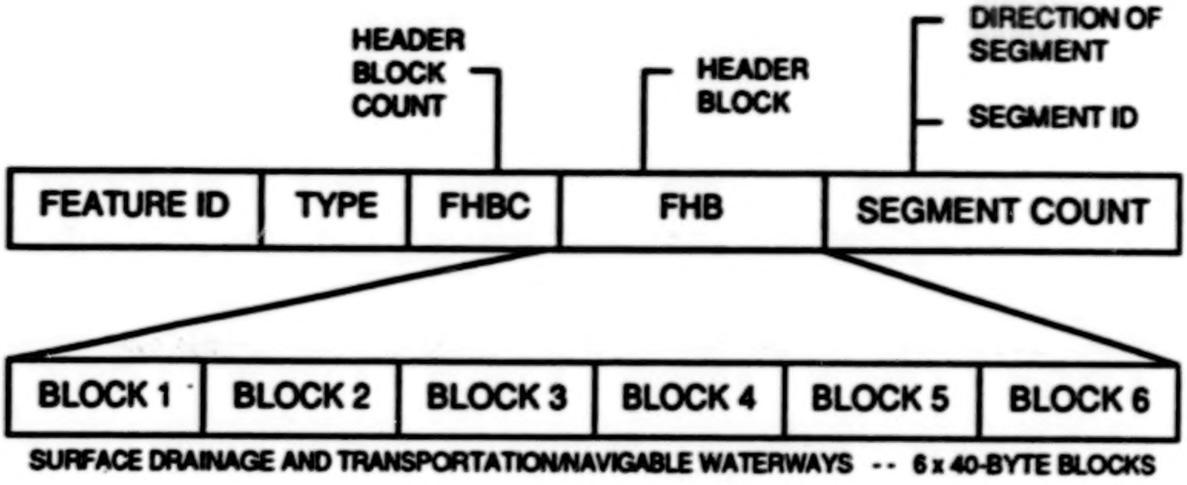
CONSIDERATIONS FOR IMPORTING MULTIPLE-ATTRIBUTE DATA

There are several alternatives for using the full feature descriptions provided by SLF. The specific approach will depend on the target system to receive the imported data, the method used for analysis of the data, and the generality desired in the import software.

Considerations for importing data to AMS must take into account that the software uses a single attribute tag for the map feature. At USAETL, the TAWS project uses a coding scheme to describe levels of information for each map feature. The coding scheme is entered when the data is digitized. Creation of terrain products in the MOSS subsystem are based on decoding a particular coding schema. One alternative for importing SLF multiple attributes would be to compress the contents of the Feature Description record into an appropriate character code. This approach involves a rule-based matching of data fields from the feature records to a locally used coding scheme. While this approach has minimal impact on existing methods for data analysis, it is limited to a particular system. Also, information from the source data may be lost in the process of compressing data fields to a coded representation.

A more generalized approach would allow the user to access any and all attribute fields that may be present in the imported data. A digital data product, such as SLF, contains varying levels of detail. The user may want to preview future information on tape to determine what may be present. The import utility would have the capability to down-load the feature information to a multiple-attribute database. The structure of the feature database could be tailored to conform to a MOSS multiple attribute file. If a data base management system were integrated to the GIS, the import software could create a generic "flat" file that could be accessed by the DBMS. These alternatives are currently being considered.

Current developments in digital cartographic exchange formats emphasize the need for flexible descriptions of map attribute data (Guptill, 1986). In order for these data products to be fully exploited by the intended users, it is important that the GIS software be able to access the feature description component of the data product with convenience and flexibility.



BLOCK 1

ITEM NAME:
Feature Category
Original Feature ID
Security Classification
Attribute Format
Map Unit Code Symbology

BLOCK 2

ITEM NAME:
Overlay Assignment
Reserved2

BLOCK 3

ITEM NAME:
Name
Map Unit Code:
Drainage Type
Gap Width - Code
Bottom Materials
Bank Height, Right - Code
Bank Height, Left - Code
Bank Slope, Right - Code
Bank Slope, Left - Code
Water Velocity - Code
Depth of SD - Code
Water State Qualifier
Traversing Feature Class
Condition / Usability
Contamination
Potability
Water Stage
Water Accessibility
Bank Slope, Right - Low
Bank Slope, Right - High
Bank Slope, Left - Low
Bank Slope, Left - High
Elevated Qualifier
Water Velocity - Low/Actual
Water Velocity - High

BLOCK 4

ITEM NAME:
Water Velocity - High
Vegetation / Obstruction
Storage Capacity - Low
Storage Capacity - High
Storage Capacity - Code
Length - Low / Actual
Length - High of Range
Length - Code
Channel Width - Low / Actual

Figure 2. Expansion of a FEA Logical Record Showing Some of the Data Fields Present for a Surface Drainage and Transportation / Navigable Waterways Feature. (Blocks 5 and 6 not shown)

CONCLUSIONS

An enhancement to AMS was developed to import a digital cartographic data base from magnetic tape. The current version translates Standard Linear Format (SLF) data to internal AMS data files. Alternatives are being considered for importing the multiple-attribute component of the SLF data product. The modular design of the system will allow a modification to import any standard vector data product with an arc-node structure (eg. USGS Digital Line Graph) to the AMS data base. The principle advantage of importing data to AMS rather than MOSS is the capability in AMS to make changes to the source data.

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APPLICATIONS

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MARKMAP: A GIS FOR SMALL SCALE MARKET AREA ANALYSIS

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ABSTRACT

Geographers have contributed substantially to the field of retail marketing, particularly in the development and application of models for market area analysis. However, few attempts have been made to apply a geographic information system (GIS) approach to market area analysis. The combination of a geographic database and appropriate thematic information in a GIS provides a foundation for an automated market area analysis system. This paper describes MARKMAP, a prototype GIS for small scale market area analysis and applied it to the problem of retail convenience store location. The geographic database consists of disaggregate locational information such as street addresses and local areal units while the thematic database defines the socioeconomic characteristics of the market at individual or aggregate levels. Spatial market segments for a particular product or service are identified and delineated by applying GIS techniques to these databases.

1. INTRODUCTION

To date, GIS applications have focused primarily on natural resource planning (Tomlinson and Boyle, 1981). GIS development began in the early 1960s as governments realized they needed an instrument to manage and monitor their shrinking natural resources properly (Dangermond et al, 1981; Tomlinson, 1984). Present developments in GIS focus on applications to land-use planning, digital terrain modelling, and digital cartographic techniques. Less work is being done on the applications of GIS to economic analysis. However, as the United States continues its transition to a post-industrial society, a larger portion of its national product will be accounted for by its service sectors. A future direction of GIS technology will be applications in marketing and retail trade.

Several systems such as the Toronto Planning Board Computer Mapping System (CTPB) have market area analysis capabilities but are not designed primarily for that purpose (Yeung, 1979). To fill this gap, MARKMAP, a GIS designed specifically for small scale market area analysis was developed. Because the combination of potential services/products with market areas is almost limitless, a prototype system was constructed for retail marketing that can be expanded to include other products/services. It is assumed that large scale analysis has narrowed the spatial domain to a local geographic area. MARKMAP's functions are those that a market planner would find necessary to evaluate any selected local market.

2. DATABASE ORGANIZATION

Any system attempting to identify and delineate market segments must be able to encode, analyze, and display socio-economic and demographic data. In the absence of an independent market study, the thematic attribute data set will most likely come from the U.S. Census of Population and Housing. All of the thematic data from this source is geographically referenced against the Bureau of the Census' DIME (Dual Independent Map Encoding) file (Figure 1). The DIME file was the first data structure to incorporate explicit topological relationships present in spatial data.

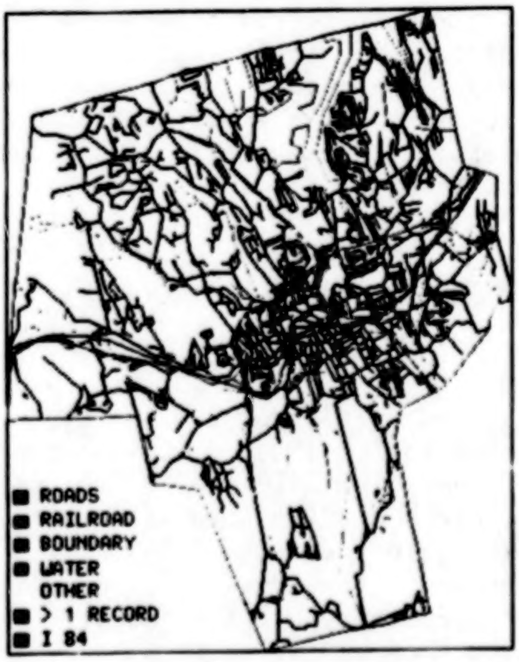

Figure 1. The DIME file for Danbury, Connecticut.

A DIME record defines the spatial attributes of individual DIME segments, straight line segments that represent a portion of a street, railroad, or some other linear feature in an urban area. For each segment, the cobounding polygon values reflect the Census Bureau's spatial hierarchy for organizing the urban environment. The highest level of spatial aggregation in MARKMAP is the Minor Civil Division (MCD). The MCD is disaggregated into census tracts, which are further divided into block groups and finally into blocks that correspond to the DIME segments. The block represents the least common geographic unit (LCGU), an area that cannot be further partitioned (Peucker and Chrisman, 1975). Any larger area can be constructed from the blocks given the hierarchical nature of the census data organization.

Although the DIME file is very versatile in application, several criticisms of the DIME structure have been made. First, the simple segment organization makes the handling of complex lines very unwieldy becuase of data redundancy (Burrough, 1986). This segment structure also makes the reduction of detail for display purposes difficult because line segments cannot be simply deleted without correcting the reference codes for the affected nodes (Peucker and Chrisman, 1975). A second drawback is that area outlines cannot be retrieved without an exhaustive search of the segment file and subsequent sorting of the relevant segments into their proper topological order for a given polygon.

To overcome some of these difficulties, MARKMAP uses extended DIME segments as the foundation of its spatial database. An extended DIME segment consists of its basic segment and its adjacent left and right segments (Figure 2). The left segment is defined as the first segment encountered when traversing the "from" node in a

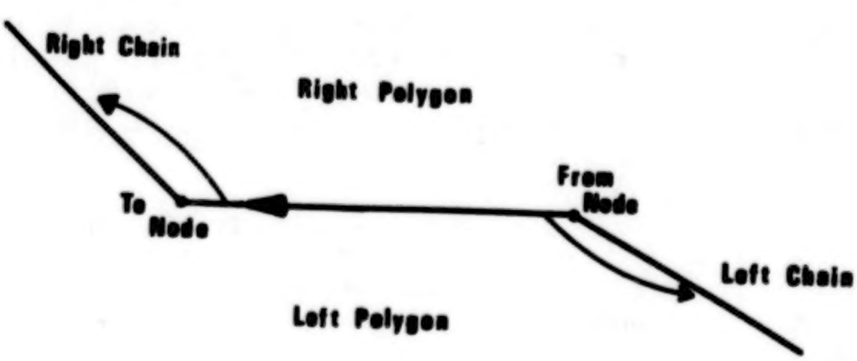

Figure 2. An extended DIME segment.

counter-clockwise direction (see Herring, 1987). The right chain is defined as the first segment when traversing the "to" node in a counter-clockwise direction. These extended segments can be assembled in a one-time pre-processing routine from original DIME segments. Once constructed, the laborious searches and sorts to construct polygon outlines are eliminated. Any outline is retrieved by using the extended DIME file as a linked list. Given one segment on a particular polygon outline, the next segment in topological order will be the left segment associated with the current segment if the corresponding polygon is the left polygon associated with that segment and the right segment otherwise.

3. SYSTEM FUNCTIONS

The pre-processing routines usually found in many general purpose GISs for constructing the geography base file have been eliminated in MARKMAP and replaced by the extended DIME segment pre-processing routine discussed in the previous section. MARKMAP's overall function organization is patterned after the census data hierarchy. The first-level functions are those performed at the MCD level: 1) data display; 2) windowing; 3) thematic attribute retrieval; 4) single-factor choropleth mapping; 5) composite mapping; and 6) market potential calculation. The second- and third-level functions performed at the census tract and block group level include: 1) data display; 2) windowing; and 3) thematic attribute retrieval.

The objectives at the MCD level are: 1) to provide the user with a detailed graphic display of the geographic domain; 2) to provide the ability to query the thematic database; 3) to perform analytical mapping; 4) to perform simple spatial modelling; and 5) to move to the census tract level. The first objective is accomplished by the display and window functions. The standard display at this level is the outline of the MCD and its census tracts (Figure 3). The standard display is enchanced by a fill option to draw the entire DIME network (see Figure 1) color coded by feature code (for example, streets, water, railroads). Windowing gives the user a more detailed graphic display of congested areas.

The second objective is accomplished by thematic attribute retrieval. The user may retrieve the values for any number of MCD attributes and either display them on the screen or write them to a storage device. The third and fourth objectives are accomplished by simple choropleth and composite mapping. Composite mapping overlays two or more attributes to determine the feasible intersection of different thematic constraints. For example, Figure 4 shows the distribution of block groups in Danbury, Connecticut, that have a population

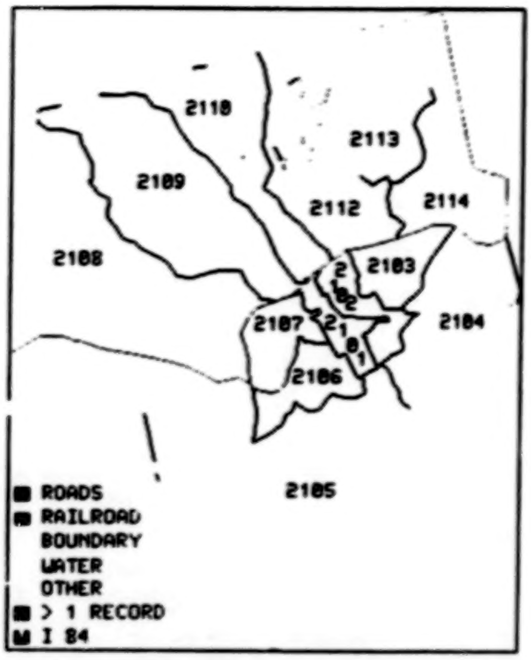

Figure 3. The standard MCD display.

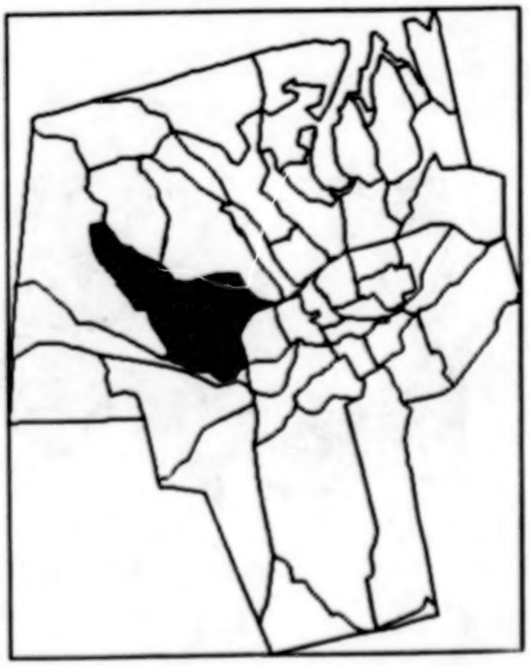

Figure 4. The distribution of block groups having more than 2500 people and above median individual income.

greater than 2500 and above median individual income. Composite mapping is useful to identify the geographic distribution of particular market segments within a region.

The spatial analysis of individual factors is aided by market potential calculation. Market potential models are traditionally demand-oriented, spatial interaction models to measure accessibility to some areally distributed phenomena (Smith, 1971). MARKMAP uses market potential to indicate growth prospects or accessibility conditions for each block group. Once market potential is calculated, it can be mapped as a thematic attribute (Figure 5).

System control is passed from level to level in the hierarchy by special functions that redefine the relevant geographic domain. The functions at the lower levels of the spatial hierarchy are a subset of the basic MCD functions.

4. AN EXAMPLE RETAIL CONVENIENCE STORE ANALYSIS

The utility of this system for market area analysis is demonstrated through an analysis of retail convenience store location in Danbury,

Figure 5. A market potential map of weighted median household income.

Connecticut. A retail convenience store is the smallest type of shopping center; its primary trade area or geographic market is composed of the immediate area plus nearby areas having no convenience stores closer than the site under investigation. Convenience stores have very small geographic markets, drawing from an area having a radius of approximately 1.5 miles depending on the density of residential use (McKeever and Griffin, 1977). For this situation, the corresponding geographic unit of analysis that satisfies the trade area radius requirements is the block group.

According to McKeever and Griffin, any market area analysis must include the following: 1) a measurement of retail sales potential and an analysis of an area's demographic characteristics, and 2) the identification of competition and access analysis. To measure retail sales potential, the market potential of each block group is calculated and displayed (Figure 5). The demand variable is median household income weighted by the number of households. The maximum retail sales potential lies in tract 2106/block group 1. The initial phase of measuring competition is mapping those block groups that contain existing convenience stores (Figure 6). The existing stores are

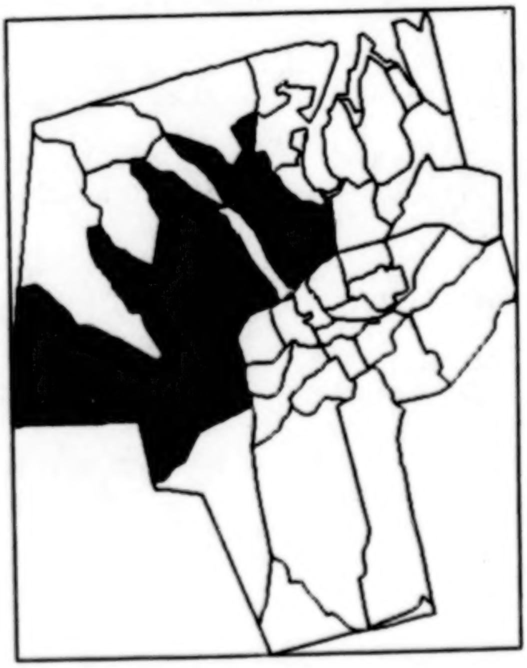

Figure 6. The distribution of existing convenience stores.

clustered in the northwest section of Danbury outside tract 2106/block group 1. The highest potential lies in an unserved area.

Finally, closer examination of the street network around tract 2106/block group 1 identified two potential barriers to access, Interstate 84 and a railway serving as the block group's northern boundary. These barriers favor location in the southeast section of tract 2106/block group 1.

5. SUMMARY

The fundamental benefit of applying GIS techniques to market area analysis is the ability to associate a market segment with its corresponding location. This synthesis of information adds a dimension to market planning--spatial analysis. This dimension allows market planners to compare and study differences in the characteristics of geographic areas as retail sites and for the potential markets they represent.

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DWRIS87 - A U.S. FOREST SERVICE GIS BUILT AROUND DATA ENTRY BY AUTOMATED SCANNING

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ABSTRACT

Eighty percent of the cost of a geographic information system - acquisition, implementation and use - is data entry. That figure is generally accepted to be true and is disputed by almost no one. Most systems seem to be totally committed to manual digitizing. The primary reasons for that commitment appears to be: 1. that it is easier to build a system around a manual digitizer than to build a system around an automated data capture device and 2. inertia. The use of automated data input requires much more programming skill and more careful system design. Tremendous savings would be available to users and potential users of GIS, if developers of GIS systems would do the necessary basic system design to include automated data entry methods. Until the commitment to manual data input is broken and the industry gets on to the development of automated data-entry, the full growth and power of GIS technology will not be realized. The Pacific Southwest Region or Region 5 of the Forest Service has a system which can serve as an example of how such data-entry problems can be solved. This paper discusses data entry concepts, considerations for systems design, and describes Region 5's Distributed Wildland Resource Information System - 1987(DWRIS87). Scanning, system procedures, system performance, and analysis and display capabilities are described. DWRIS87 is not only proof that scan digitizing is feasible, but makes it difficult to defend manual digitizing as a reasonable data entry option at all.

1. INTRODUCTION

A geographic information system (GIS) can be a very valuable and powerful tool in the scheme of resource management. However, there is one major drawback in the use of GIS and that is the cost of data entry. Many potential users of GIS are precluded from GIS technology by the high cost of data entry. It is commonly agreed that the data entry phase of GIS use is in the neighborhood of eighty percent of

the cost of implementation and use of a GIS. The reason for this large cost is almost total reliance of the GIS industry on manual digitizing as the standard data entry method. Automated data entry can reduce the cost of data entry by at least ninety percent, probably more. In order to take full advantage of automated data entry, a system should be designed around the input device. Just taking a scanner and inserting it into a system designed around manual digitizing will not take full advantage of the scanner's capabilities and flexibility. It is a rare system, indeed, which is built around automated scanning for GIS data capture. The Pacific Southwest Region, or Region 5, of the Forest Service has such a system.

2. DATA ENTRY CONSIDERATIONS

The GIS industry as a whole seems to be avoiding the question of manual data entry versus automated data entry. Why should it avoid a technique which has so many potential benefits for the GIS user? In order to understand this we must understand the nature of GIS data entry

Map data is analog data and computers require digital data. To analyze and manipulate maps in an efficient manner, the maps need to be put into a form that computers can read. If we want to put mapped information into these digital devices, we need to make an analog to digital conversion of this information.

One name for analog to digital conversion of map data is rasterization. All methods of GIS data entry involve rasterization of the map. Manual digitizers are controlled by the human hand, scanners are controlled by computers, and control of automated line followers involves both. In manual data entry systems, rasterization is accomplished as a person mimics the analog features of a map by moving a cursor over these features. The more detailed or complex a map, the more difficult and time consuming the rasterization will be.

Rasterization by a scanner is much simpler. The scanner perceives the map as a series of rows and columns of pixels of a uniform size. It assigns each pixel the value of a step or grey level somewhere between white and black. Using this information supplied by the scanner, the computer decides whether each pixel is part of a line or background. This is done methodically, and very rapidly, one row

at a time. The scanning process is independent of the complexity of the map and digitizes all maps of the same size in the same amount of time. A scanner will digitize in a few seconds or minutes a map which would require days or weeks for a skilled manual digitizer to complete.

3. SYSTEMS DESIGN CONSIDERATIONS

A basic difference between automated and manual data entry is the vectorization process. The manual digitizer gives you vectors directly, apparently. With scanning, vectorization is accomplished in the computer.

When automated scanning is the input procedure, a high level of system design will be required to get into the GIS business. First of all a vectorization scheme is necessary. That vectorization scheme will require a very carefully thought out data structure. If one is going to that much trouble, an efficient scheme of data storage and manipulation should be worked out as well. At that point the seeds of an efficient, useful, user-friendly system will have been sown.

When one chooses manual digitizing as the data capture method, system design may not seem as important. After all, the digitizer has provided the most difficult part of the system. It gives you your vectors. Buy a manual digitizer, a micro-computer, a graphics package, write some software to link it all up and add a few analysis features and be in the GIS business. Later additions of features may be more difficult or haphazard because of a lack of good system design. This will tend to make the system less efficient and less user-friendly over time. It is analogous to painting yourself into a corner.

Being handed vectors by the digitizer has at least two disadvantages. First, it means you have to edit vectors, a much less efficient method of editing than raster editing. When editing vectors, nodes or branchings can prove difficult to resolve. With raster editing, nodes may be identified before or after the editing is finished, and nodes may be modified to appropriate conformations automatically by the computer. Second, you will have to overlay vectors. Overlaying vectors is much less efficient than overlaying rasters. The system in Region 5 used to overlay vectors on a large mainframe computer. We currently overlay rasters on a 32bit

mini-computer. On the mainframe an overlay often took far more than an hour. The process on the minicomputer takes around two minutes. When overlaying rasters, every point on one raster is overlaid on the other raster. Typically, when overlaying vectors, point thinning of line segments is done to save on processing time. Point thinning when overlaying introduces slivers, many more than raster overlaying. This may introduce a significant error into your database which will increase with each new layer overlaid.

Use of a manual digitizer, then, can allow for the piecemeal approximation of system design. A scanner, on the other hand, will require the sound long-term system design which should be used for systems as complex as GIS anyway. It would seem that system builders or vendors are too complacent to computerize vectorization; are stuck with a system design which cannot handle it; or do not have the talent or imagination to do the job. The industry's inertia might be understandable, but it is difficult to understand the rser's complacency with a situation that is costing them far more money than it should. Scanners which can do the data entry job are available. They cost as little as $200 with many in the $1000 - $30000 range.

4. SYSTEM HISTORY

In the late 1960's the Pacific Southwest Forest and Range Experiment Station (PSW) and the Pacific Southwest Region or Region 5 of the Forest Service began development of a GIS which came to be known as the Wildland Resource Information System (WRIS). WRIS was written in Fortran V and ran on a large mainframe computer. The system was converted to run on a second computer at Washington State University and on a third computer at Oregon State University in the 1970's. In 1980 WRIS became part of the Forest Service interim GIS, and was renamed RID*POLY (Resource Information Display*Polygon). RID*POLY was then installed at the U.S.D.A. computer center at Fort Collins, Colorado. Recently the system was completely redesigned, based on the last sixteen year's experience, to run on the 32bit mini-computers purchased by the Forest Service, and is now called the Distributed Wildland Resource Information System - 1987 (DWRIS87). The system may now be used by the individual National Forests and District offices on their own equipment.

Region 5 has been using scanners for production data entry for over sixteen years. In 1971 the PSW station developed a way to automatically convert map data into a computer readable form using a microdensitometer. Production runs using the microdensitometer and

the new WRIS software began in the fall of 1971 with maps from the Stanislaus National Forest. Results of the analysis of the overlaid maps were used in designing a timber inventory and management plan for the Forest.

By 1974 the Region had entered the maps of three forests and decided they needed a faster input device. The microdensitometer took from 9 to 13 hours to scan a single map and data entry had become a bottleneck. A scanning drum microdensitometer was purchased that year reducing the time necessary to complete a scan of a map to 5 - 20 minutes. Even further time reductions were realized in 1982 with the purchase of a faster scanner to support the Region's Land Management Planning effort. The new scanner accomplished the scans in 1 to 2 minutes.

5. SYSTEM PROCEDURES

In the Forest Service planning process, maps of different thematic content are usually prepared by the resource people on the National Forests. Timber management people develop timber stand or vegetation maps; soil scientists develop soil maps. Maps are drawn which include land status, administrative constraints, physiographic constraints, or whatever information is deemed necessary to the responsible management of the Forest. The maps are entered into the GIS, overlaid and the results displayed and/or used as input to linear programs which aid Forest and Regional officers in determining management of the Forests. Other data sources are becoming more important. Digital data from satellite imagery and the Forest Service Geometronics Service Center in Salt Lake City are currently being entered into the GIS also.

In order to enter a map into DWRIS87, it is photographically reduced by a factor of 8 to 10 to fit a 4"x6" negative. The map originals are usually 7.5 minute quadrangles at 1:24000 scale. A 10X reduction yields a photographic negative image approximately 1.75" by 2.5" or 44mm by 59mm. The detail of the mapped information and the quality of the map drafting will determine the amount of reduction. A very good quality map will be reduced more than a poor quality map, a very detailed map will be reduced less than an uncomplicated one.

This negative reduction is then scanned and entered into the computer as digital data. In order to extract the information we require from the negative, we must define for the machinery -

scanner and computer - what is useful information and what is not. We are essentially interested only in line information. A given point on the negative is either part of a line or it is not. If it is part of a line, we characterize it as a "1" or an "on" bit. If it is not part of a line it is background and can be characterized as a "0" (zero) or an "off" bit. This is binary information - yes or no, on or off.

The scanner can perceive much more detailed data than binary or one-bit data. It can perceive eight-bit data and distinguish 256 different "grey" levels - 0 to 255 - from complete opacity to light to complete transparency to light. The camera optics on the scanner are such that we can define a sampling spot or pixel of from 16 microns to 60 microns in size as imaged on the system's sensor, a diode array. The density class assigned to each pixel is dependent on the total amount of light sensed by the diode. If the pixel is background, the light sensed will be very low; if line,the light will be very high; and if the pixel is partially line, the light sensed will be somewhere between the extremes, depending on the proportion of the pixel which is light.

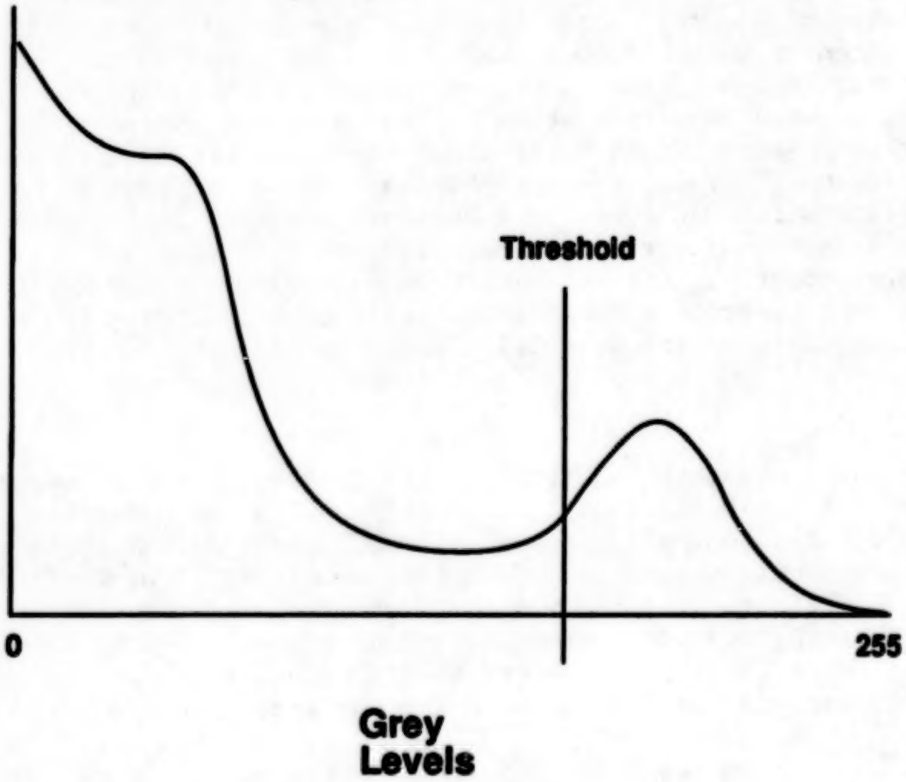

Figure 1. Bimodal scanning density distribution.

A 7.5 minute quadrangle at a scale of 1:24000 reduced 10 times and scanned at a pixel size of 50 microns will yield a two dimensional binary array of data approximately 900 pixels by 1200 pixels, for a total of over a million pixels. The first time we scan a negative from a uniform batch of negatives we compile a frequency distribution which gives us the number of pixels which fall into each of the 256 density classes (Figure 1). This frequency distribution is bimodal in nature with one large mode expressing background and one smaller mode indicating line. A class somewhere between the two modes is selected and used as the scanning threshold for that batch of negatives. All classes below that threshold are considered background and are assigned the value "0" and all classes greater than or equal to the threshold are considered line and are assigned the value "1". The result is a scan file written to disk containing the binary representation of the map.

This scan file or binary map is the raw data and needs to be cleaned up in order for the programs of DWRIS87 to convert the binary map into the vectorized approximation of the original map. The "lines" may be several pixels thick. There may be gaps in the lines. Lines may have "melted" together. The raster may contain extraneous information or noise. Before editing, the lines are thinned to a width of one bit by a skeletonizing program. Next, all the nodes need to be located and stored with information concerning their conformation. This binary map can be printed on a line printer or displayed on a video terminal with the background characters suppressed for editing. The binary map is edited or cleaned up interactively. Individual bits, or strings or blocks of bits, in the raster are turned on or off to create lines or continuities where they belong, or remove line information from areas where they do not belong. Gaps in lines may be plugged automatically or interactively. Lines which "melt" together because of their close proximity to one another are corrected interactively by deleting bits to separate the lines. Figure 2a. is a typical example of a small piece of an unthinned and unedited map. The numbers on the margins of Figures 2a. and 2b. identify the rows and columns in the raster where these features are found. For editing purposes, the background zeros are suppressed and the ones are converted to "0"s to make line interconnections easier to see. This section from a land status map shows lines of more than one pixel thickness, a gap in a line and some extraneous noise. In Figure 2b. we see the section of the map following thinning and editing. The lines have all been thinned to one bit, the gap has been filled either interactively or automatically, and the noise has been eliminated automatically and interactively.

```
   505  510  515  520  525  530  535  540  545  550  555  560
    -----+----+----+----+----+----+----+----+----+----+----+----+
31  -
32  -
33  -00000000000000000000 0  0
34  -000000000000000000000000000000000000000000000000000000000000
35  -    +    +    +    +    +    +    +    00   +    +    +    +
36  -                                       0
37  -                                       0
38  -                                       0
39  -                    00
40  -    +    +    +    000  +    +    +    +    +    +    +    +
41  -                     0
42  -                                       0         0
43  -                                       0
44  -                                       0
45  -    +    +    +    +    +    +    +    0    +    +    +    +
46  -                                      00
47  -  00000000000000000000000000000       00
48  -  00            000000000000000000000000000000000000000000
49  -  00                                  0000000000000000000000
50  -  00+    +    +    +    +    +    +   00    +    +    +    +
```

Figure 2a. Section of an unthinned and unedited binary map.

```
        505  510  515  520  525  530  535  540  545  550  555  560
    -----+----+----+----+----+----+----+----+----+----+----+----+
31  -
32  -
33  -00000000000000000000
34  -                    0000000000000000000000000000000000000000
35  -    +    +    +    +    +    +    +    0    +    +    +    +
36  -                                       0
37  -                                       0
38  -                                       0
39  -                                       0
40  -    +    +    +    +    +    +    +    0    +    +    +    +
41  -                                       0
42  -                                       0
43  -                                       0
44  -                                       0
45  -    +    +    +    +    +    +    +    0    +    +    +    +
46  -                                       0
47  -   0000000000000000000000000000        0
48  -   0                           000000000000000000000000000
49  -   0                                   0                  00
50  -   0+    +    +    +    +    +    +    0    +    +    +    +
```

Figure 2b. Section of the binary map following thinning and editing.

The clean binary map or raster is next run through a program which vectorizes the raster. This program vectorizes the paths between the nodes and assembles the polygons, if it is a polygon map. All paths are numbered and stored in a file. Polygons are stored with pointers to the paths with which they are built. The polygon files also contain the holes which contain any "islands" or island groups found within the boundaries of a polygon. Entry of point and line data is also provided for.

After the paths and polygons have been vectorized the map is run through a program which makes various calculations on them. This program calculates the area of each polygon, the perimeter length, computes a label coordinate and sets up a file to hold this information. Next, labels are assigned and connected to the appropriate polygons with a labeling program.

6. SYSTEM PERFORMANCE

One might ask the time required, in DWRIS87, to accomplish the various operations on a typical map of 800 polygons. Depending on the computer load - i.e. light versus heavy computer use the following wall clock times are typical.

Scanning	2 to 4 minutes
Editing	5 to 30 minutes
Vectorization	9 to 20 minutes
Calculations	12 to 30 minutes
Overlay	2 to 4 minutes

(Overlay is raster and the result must be vectorized and the polygon calculations must be made.)

More important than times for individual steps or programs is the question of through-put: How many maps can be run through the system to completion in what period of time?

A year ago, in the first production run of this latest incarnation of WRIS, one person, with little peripheral help, scanned and edited 119 vegetation maps, averaging 500 polygons per map (as few as 10 or 20 to as many as 1100 or 1200) in fourteen working days. I do not believe the manual digitizing system exists that can come anywhere close to that level of data capture. The system is now menu driven and that job could be done even quicker today. With the menus the entire Forest can be overlaid, including sliver resolution,

overnight with a single command. The system is so efficient that it does not require its own dedicated computer. Raster editing is done on video display terminals; therefore, expensive manual digitizing work stations are not required, keeping hardware costs down.

7. ANALYSIS AND DISPLAY CAPABILITIES

Analysis at this point is limited to overlaying and the Boolian operations "and", "or", and "not", which can be run on any subset of polygon characteristics. The overlay is very simple and extremely fast. Maps of differing scales may be overlaid. The rasters of multiple layers are transformed into each other. The resultant raster must then be thinned, vectorized, calculations run, and labels assigned and concatenated, and sliver resolving programs run if desired. The price paid for the simplicity of this approach is reprocessing the resultant rasters each time an operation is made on a raster. The speed of the processes is such that it is a small price to pay. Boolian analysis of the map is accomplished by creating a selections file which contains all the classes to be included in the analysis and an equation describing the interaction among the classes to define the desired subset. This subset may then be plotted or tabular information reported, or a new map created. More analysis features are planned in the near future.

8. CONCLUSIONS

Since this level of data capture is possible, why should any GIS user put up with much slower, much more expensive data capture methods. This is no trivial question for a large land manager such as the Forest Service. Anyone involved in endeavors requiring GIS technology should have better uses for their funds than outmoded data capture methods.

For instance, the Forest Service is currently looking very closely at geographic information technology. GIS is a very topical issue. Many in the Forest Service are involved in evaluating this technology. Using the knowledge acquired in this process, the Forest Service is going to have to decide how best to go about acquiring the tools necessary to manage and analyze its spatial resource information within the higher construct of its corporate information system. The question will be "Is the technology required available or must it be developed?"

Two major considerations in this process will be information structures and data-entry. Given the massive data-entry job involved in getting the Forest Service as a whole into the world of GIS, the data-entry method will have to be extremely efficient. It will have to be automated. It is inconceivable that the hundreds of millions of dollars that manual data-entry would cost could be justified to the people who pay the bills. The Pacific Southwest Region of the Forest Service has been guided by the concept of efficiency of data-entry since the beginning of its GIS activities. This will certainly be true of the Forest Service as a whole as it moves into this necessary technology of information management.

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THE USE OF USGS 1:100,000 SCALE DIGITAL DATA AS A BASE MAP SOURCE FOR AUTOMATED FLOODPLAIN MANAGEMENT

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ABSTRACT

The Federal Emergency Management Agency (FEMA) is tasked with administering the National Flood Insurance Program (NFIP). In performing this mission, FEMA has provided flood hazard mapping for over 18,000 communities nationwide. The magnitude of this spatial data set of flood-related information has led FEMA to investigate the possibility of incorporating Geographic Information Systems (GIS) technology into management of NFIP activities.

One of the initial steps in the evaluation of GIS application to the NFIP has been the identification of appropriate sources of digital base maps for flood hazard information. A review of existing data bases and developments in the computer mapping field has led to the conclusion that, as the result of the efforts of local governments, some base mapping may be available in digital form for a limited number of NFIP communities. However, the only digital base map source of national extent is the U.S. Geological Survey (USGS) 1:100,000-scale digital data base.

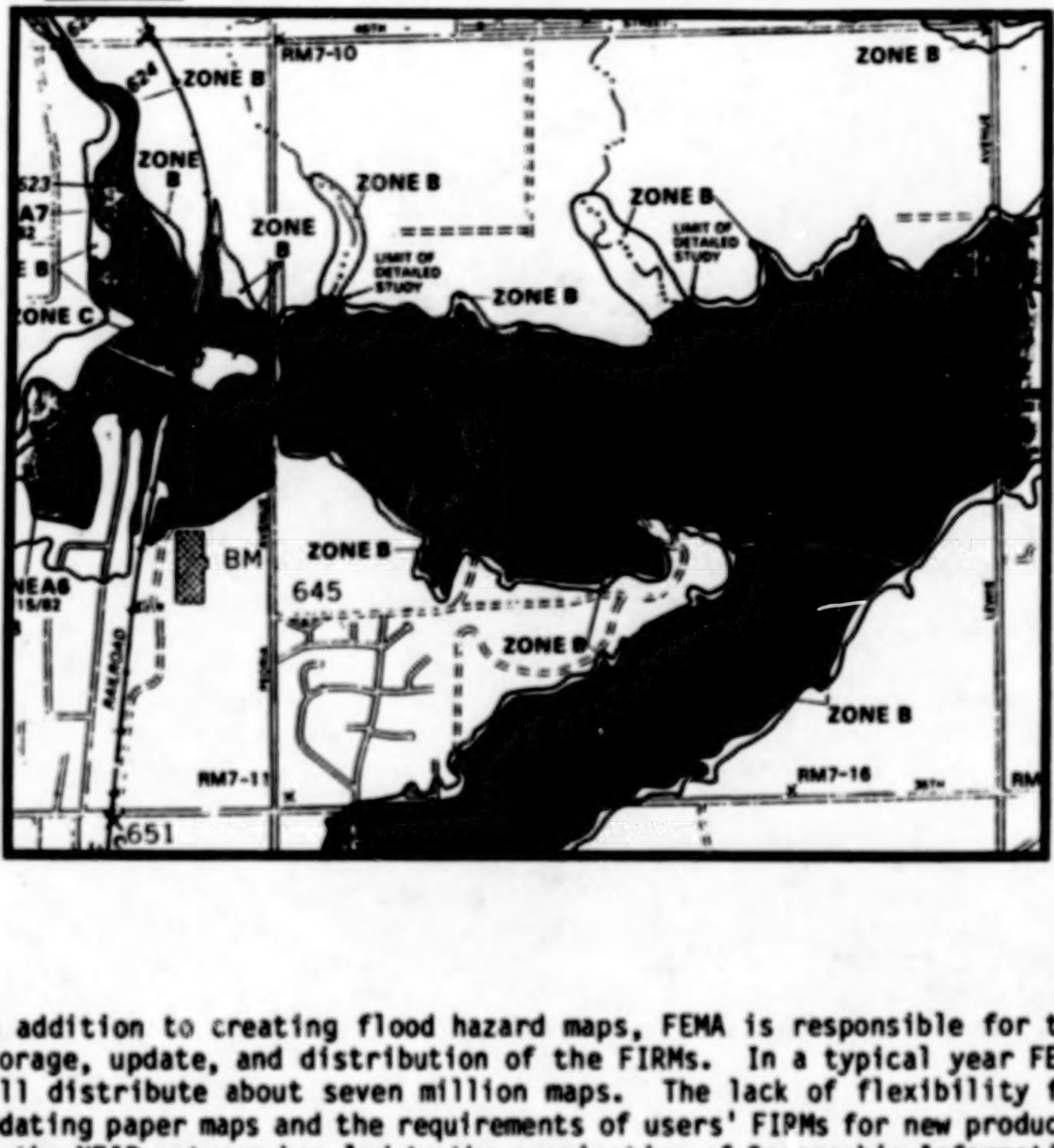
Because of the relatively small scale of these data, FEMA has conducted tests to determine if the digital 1:100,000 can provide an adequate source of base maps for flood hazard maps, which are typically published at scales ranging from 1:6,000 to 1:24,000. This paper summarizes the results of FEMA's testing of the horizontal position accuracy, completeness, and line geometry of the USGS 1:100,000 scale digital data base transportation layer.

1. INTRODUCTION

The National Flood Insurance Program (NFIP) is administered by the Federal Emergency Management Agency (FEMA), an independent agency within the Executive Branch of the Federal Government. Participation in the NFIP is voluntary and open to counties or local jurisdictions with floodplain management authority. Since the inception of the NFIP in 1966, flood hazards have been mapped in over 18,000 communities nationwide (1). The flood hazard maps prepared by FEMA, known as Flood Insurance Rate Maps, or FIRMs (Figure 1), depict areas that would be inundated by a flood having a one-percent probability of being equalled

or exceeded in any given year. This area is normally referred to as the 100-year floodplain. 500-year floodplains; regulatory floodways; coastal high hazard areas; 100-year, or base, flood elevations (BFEs); hydraulic cross sections; and insurance risk zones are also shown on the FIRMs.

FIGURE I: EXAMPLE OF PUBLISHED FIRM FOR THE CITY OF TULSA



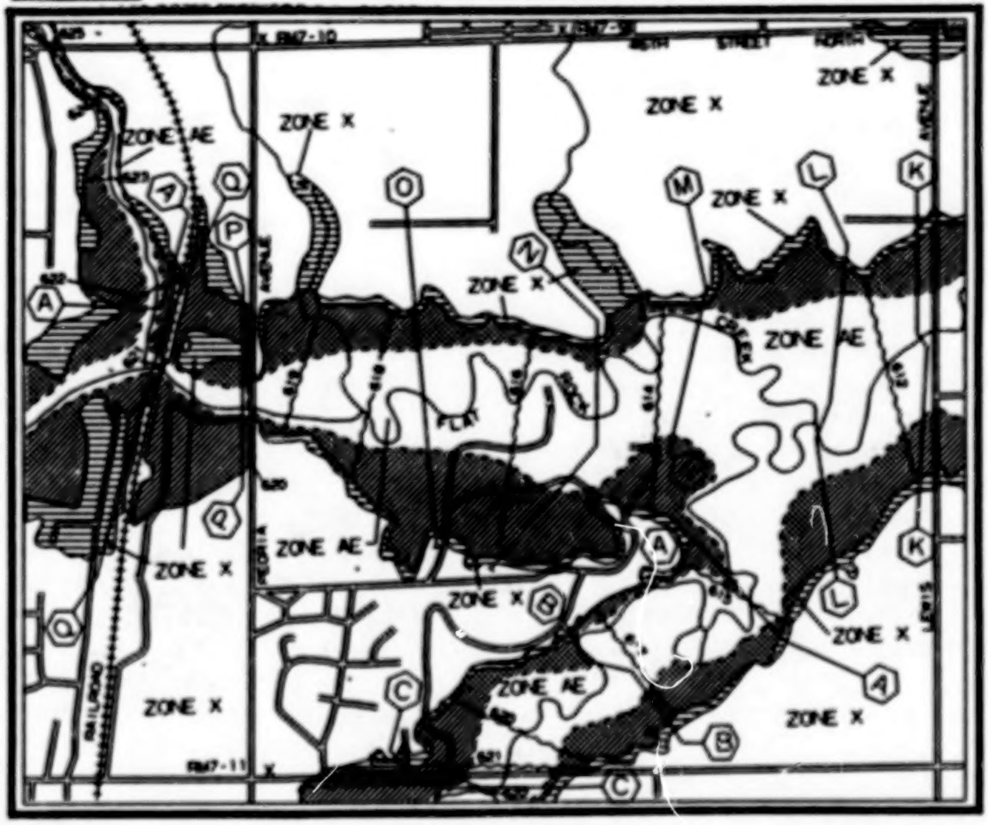
In addition to creating flood hazard maps, FEMA is responsible for the storage, update, and distribution of the FIRMs. In a typical year FEMA will distribute about seven million maps. The lack of flexibility for updating paper maps and the requirements of users' FIRMs for new products as the NFIP matures has led to the examination of Geographic Information Systems (GIS) technology by FEMA for automating map related activities of the NFIP.

2. CONCEPT FOR APPLYING GIS TECHNOLOGY TO THE NFIP

In administering the NFIP, FEMA is tasked with providing information on flood hazards. This information can be conceptualized as a thematic element within a GIS. FIRM data within the GIS can serve the needs of multiple users and applications without the requirements for manual

transfer of data between map sheets, such as between a FIRM and a community zoning map, and provide a mechanism for rapid update of FIRM data. Past tests by FEMA have demonstrated that FIRMs can be produced through the application of computer mapping technology (2) (Figure 2).

FIGURE 2: PORTION OF COMPUTER GENERATED FIRM, FY 86 PILOT PROJECT



Digital base mapping to provide the underlay for thematic FIRM information is required before any useful application of digital flood hazard data can be performed. Even given the existence of digital base mapping similar to that currently used for hardcopy FIRMs, new products are being requested of the NFIP that require more extensive knowledge of community geography than that provided by current hardcopy mapping. Perhaps the most important need is to rapidly and accurately determine if particular parcels of land are within flood hazard areas. To answer questions of this nature digital data capturing parcel geography is required.

Such data sets are beginning to be developed by local communities within the United States in response to their own needs. A survey of the 100 NFIP communities with the largest number of flood insurance policies showed that 17 of the 51 responding communities had computer mapping capabilities of some type (3).

FEMA is presently engaged in testing the feasibility of combining digital FIRM data with community-developed digital parcel mapping. However, communities with digital parcel data are few at present. Alternative sources of digital data, both for parcel data and also for digital FIRM base mapping, are required if the objective of automating NFIP map activities is to be reached.

3. REQUIREMENT FOR PUBLIC DOMAIN DIGITAL DATA

Digital data sets are of two primary types, public domain and proprietary. Public domain implies that the data set was developed by a public agency at the taxpayers expense, is not classified, and is therefore available to any member of the general public for no or at a minimal cost. Proprietary data are data whose use is restricted, either by security classification or because the data set was developed by a private vendor who charges a fee for use or copies of the data base.

When GISs are designed, the sources of data for the system and the users of the system must be considered. Any data base to be utilized by the NFIP must be without the restrictions imposed by proprietary data sets. Many NFIP communities probably would be reluctant to use a digital system if there are costs to acquire base map data that is currently free with hardcopy FIRM products. Further, to encourage the widest possible dissemination of knowledge concerning flood hazards, it is in the Federal Insurance Administration's (FIAs) best interest to avoid developing a digital data base that in any way, either due to cost or security issues, restricts access to data. Particularly at the inception stage, when possible system users may be confronted by difficulties associated with acquiring, operating, and understanding computer hardware and software, obstacles such as access to data should be minimized. For these reasons, although there are sources of proprietary digital base map data, particularly from utility companies, the focus of FEMA in developing a concept for automating flood hazard mapping has been on the public domain data sets.

4. AVAILABLE PUBLIC DOMAIN DATA SETS

Many Federal agencies of the United States are involved in the creation of digital data for some applications for some areas of the country. The nature and resources of these organizations vary, as do the standards and machinery by which the data are created. The best source of information to find a way through this maze of application related digital mapping is the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC). The FICCDC was established by memorandum from the Director of the Office of Management and Budget (OMB) on April 4, 1983, to foster cooperation and prevent duplication of effort among Federal agencies involved in digital cartography. Since the inception of the FICCDC, it has been administered by the USGS. Each year the USGS has prepared a report to the Director, OMB, on the activities of the FICCDC. These year-end reports include a great deal of information on the efforts of Federal agencies to create and manage digital data (4, 5, and 6). A second source of information on the availability of digital data is USGS Circular 817 (7).

The USGS and the Bureau of the Census (Census) were identified as the only sources of digital data available to FEMA that have digital data bases both pertinent to NFIP missions and which offer national coverage. The USGS, through its National Cartographic Information Center (NCIC), is developing a National Digital Cartographic Data Base (NDCDB). At present, the USGS has made a quantum leap in providing digital base map data by completing the digitizing of the transportation and hydrography layers of the 1:100,000-scale topographic map series. Additionally, digital data bases concerning geographic names and the 1:2,000,000 National Sectional Atlas Maps are available from the USGS.

The Census has available a considerable amount of information concerning demographics. Some of these data, related to the boundaries and populations of census tracts, are available for the entire nation. Other data, such as the GBF-DIME files, are only available for a limited number of Standard Metropolitan Statistical Areas (SMSAs). A total of 345 GBF-DIME files presently exist. These files are for sale by the Census to the general public. Presently, the Census is updating and correcting the GBF-DIME files for their inclusion in the new Census digital data base, known as the TIGER (Topologically Integrated Geographic Encoding and Referencing) file (8). When the TIGER data set is completed, the GBF-DIME files will be incorporated and these data will no longer be available from the Census. The TIGER files, which will incorporate all GBF-DIME file information, will be for sale by the Census, probably starting in 1991. The USGS 1:100,000-scale digital data is being used by the Census as the geographic base for the TIGER files.

TIGER files will contain detailed data on roads, parcels, zip codes, and addresses, data of particular usefulness to FEMA (9). However, to protect the privacy of individuals, the Census will only release data by street blocks. Thus, much like the GBF-DIME files, information will be provided by address ranges for blocks. From block information, clear determinations as to whether or not a given property is located within the floodplain can not be made in all instances in response to inquires. However, a great many address ranges in the nation are either clearly within, or are entirely excluded from, the Special Flood Hazard Area (SFHA) as shown on the FIRMs. When this information becomes available for the entire nation in the form of the TIGER files, it will provide FEMA with a very strong data set for making generalized analyses of flood-prone addresses.

The USGS 1:100,000-scale digital data provides the road network and hydrographic data for the Census TIGER files. The lower 48 states are covered by 1,823 1:100,000 maps. The USGS has produced three digital files from each digital map: Transportation, Hydrography, and Miscellaneous Transportation (10). These data represent a detailed, complete digital base map for the United States and are the only public domain option currently available for digital FIRM base mapping.

In the future, the USGS does have plans to complete digitizing of all data, both planimetric and topographic, from the 7.5-minute quadrangle map series (11). It is expected that it will be the mid-1990's before

these data become available in any quantities, and the year 2000 before the entire effort is completed.

5. USGS 1:100,000-SCALE DIGITAL BASE MAP DATA

The USGS 1:100,000 maps, formally known as 1:100,000-scale metric topographic maps, were compiled from USGS 1:24,000, 7.5-minute quadrangle maps. In general, the 1:24,000 mapping dates from the mid-1960's to the late 1970's. The dates of the 1:24,000 source maps used for compilation of a 1:100,000 map are listed on the 1:100,000 sheet. Generally, the 1:100,000 maps include updates to planimetry using aerial photographs during the 1980's.

Each 1:100,000 map is the result of rescaling 1:24,000 data to the 1:100,000 scale. One 1:100,000 map, which covers a rectangular area 30 minutes in north/south extent by 60 minutes in east/west extent, covers the same area as 32 1:24,000 maps. An example of a portion of a 1:100,000 map is shown in Figure 3. Since the maps were compiled from source material of a much larger scale, the 1:100,000 maps contain a great deal of detail, particularly concerning the road network. Figure 4 provides an example of the area covered by a 1:24,000 map at the 1:100,000 scale.

FIGURE 3: PORTION OF USGS 100K HARDCOPY MAP (AT SCALE)

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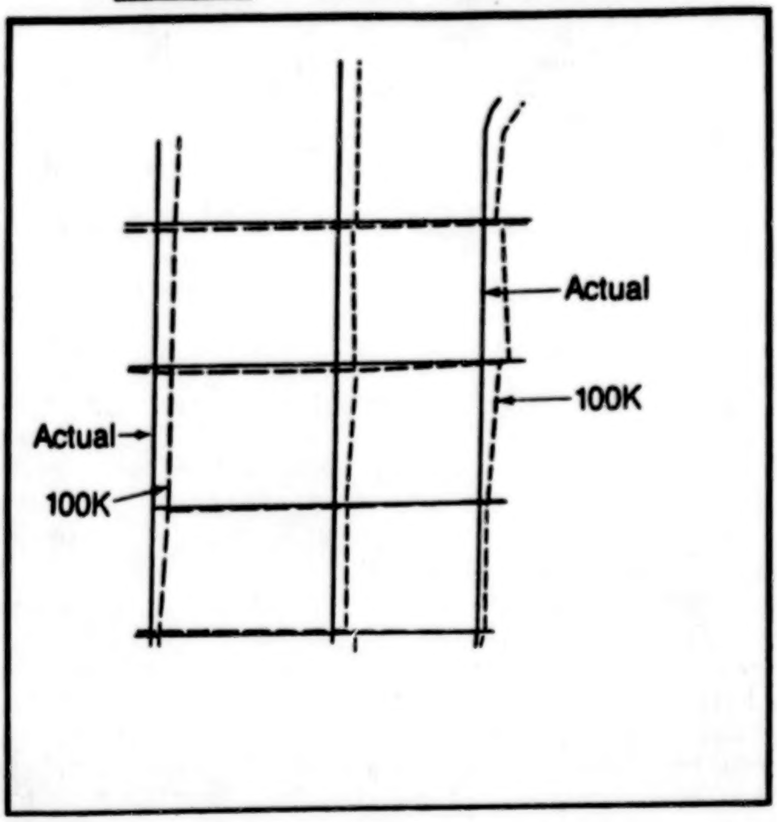
FIGURE 4: 7.5" QUADRANGLE MAP AREA AT 100K SCALE (NORMALLY ABOUT 19 x 23 INCHES)

As noted earlier, the USGS digitized three topics, or layers, of information from the 1:100,000 maps. The data capture was performed by using devices that scan hardcopy maps and record grey tone or color values for small rectangular portions of the target map. These small rectangles, called rasters, provide an electronic image of the map that can be used to regenerate an exact replica of the map. The raster data encoded by the scanning device can be analyzed by software to provide information on lines within the imaged map. This process of taking raw raster data and then analyzing these data to develop computer files of points and lines is called vectorization. The vectorization process advances the ability to use the scanned map data by providing intelligence to the electronic image of the map. Lines created through the vectorization process can be analyzed in a variety of ways and used to create new maps and information by conventional computer mapping software systems.

The process of moving from the raw scanned data to a clean vector file is not straightforward. It involves a number of steps and, although much of the work is performed in an unsupervised fashion by the computer, operators and quality control personnel must edit, check, and clean up problems either created by the vectorization software or introduced due to the inability of the software to resolve certain types of problems. Some of the problems that result from the vectorization process appear in the 1:100,000 digital files. The USGS has provided a quality product that meets map accuracy standards at the 1:100,000 scale. When these data are viewed at larger scales, however, some of the problems introduced by vectorization become evident.

Figure 5 is an example of vectorization problems at road intersections. The actual road intersections have clean, right-angle corners. However, due to the limitations of vectorization software in determining the correct centerlines of roadways from the scanned raster data, the vectorized line will often appear stretched, or skewed, at intersections. Such problems as these can be corrected by interactive edit of the digital data set. In the USGS 1:100,000 data set, most gross problems have been identified and eliminated. When the data are used at scales larger than the scale of the source mapping, the implication of these problems must be considered.

FIGURE 5: VECTORIZATION ANOMALIES



6. EVALUATION OF USGS 1:100,000-SCALE DIGITAL DATA AS THE SOURCE OF FIRM BASE MAPPING

In evaluating the use of USGS 1:100,000 data as a source of base map information for FIRMs, consideration must be given to a number of issues. As pointed out in the previous section, there are inherent difficulties in attempting to take a small-scale digital product and enlarge it for use at other scales. The minimum scale of FIRMs is 1:24,000. The maximum scale used for flood hazard maps is 1:4,800. Problems anticipated by scale enlargement of the digital data are positional accuracy, lack of detail, and quality of line geometry.

Map standards of the USGS require that 90 percent of points on a map be positioned within one-thirtieth of an inch of their true location on the earth at map scales larger than 1:20,000, and that 90 percent of points be located within one-fiftieth of an inch at map scales smaller than 1:20,000 (12). Thus, at the 1:24,000 scale, the requirement is for 90 percent of points to be located to within 40 feet of their actual location on the face of the earth. At the 1:100,000 scale, the accuracy standard is equal to 166.67 feet. This large difference between required map scale accuracy leads to concern over the use of digital 1:100,000 data at scales appropriate for FIRMs.

A second difficulty in the use of the digital 1:100,000 data that would be anticipated is the completeness of data. At the 1:100,000 scale, features less than 2,000 feet long are not normally included, while at the flood hazard map scales, features in the range of tens of feet in length may often be important in determining the location of structures.

The third problem to be assessed is the quality of line geometry as scales are enlarged from 1:100,000. At a scale of 1:100,000, only a very few points may be required to describe a curving segment of a roadway. However, at a larger scale, far more points may be needed. When a digital product is prepared for use at one scale only, the minimum number of points may be recorded to describe the feature correctly at the given scale. This helps save computer storage space, keeps down the costs of manipulating data, and enhances the speed at which computer mapping operations may be performed. But, when these data are used at a larger scale, the result may be "blocky" appearing line features with angular corners instead of smooth curves.

To evaluate the positional accuracy of digital 1:100,000 data, two sets of the 1:100,000 data were obtained. These sets were for Tulsa, Oklahoma, and Chickamauga, Tennessee. The Tulsa set was used since digital data developed from USGS 1:24,000 mapping were already available for comparison with the 1:100,000 data from a previous FIA digital mapping project. The Chickamauga data set is the USGS demonstration data set for the 1:100,000 digital data.

Testing was performed through grid cell sampling. A regular grid with 15 arc second spacing was established for the Tulsa, Oklahoma, USGS 1:24,000 map and for the Ft. Oglethorpe, Georgia-Tennessee, 1:24,000 map. Grid cells were identified by their row and column positions. For each of the 1:24,000 maps, 40 grid cells were selected at random for testing.

The digital data previously created for the Tulsa USGS 1:24,000 map were overlaid on the Tulsa 1:100,000 digital data in the Intergraph World Mapping Software (WMS) environment. The WMS software was used to measure the difference between road intersection locations as portrayed by the 1:24,000 mapping and the 1:100,000 mapping. Difference measurements were made for all road intersections within grid cells selected for sampling. The differences between the road intersection locations were recorded in feet.

Digital files from the 1:24,000 mapping did not exist for the Ft. Oglethorpe 1:24,000 map. To perform the required testing, the road intersections locations were digitized. This digital file of road intersections was compared with the Chickamauga 1:100,000 data set in the same manner as applied in testing the Tulsa data set.

The test results indicated that the sampled 1:100,000 data road intersections were, on an average, correct when compared with 1:24,000 data to within 55 feet, and 90 percent of the 1:100,000 sampled data set road intersections were located correctly to within 100 feet. Errors introduced by the creation of a digital file from the 1:24,000 data for comparison to the 1:100,000 data were assumed to be negligible. Multiple setups were performed to assure proper horizontal control of source 1:24,000 maps during data capture. The data capture was performed on a digitizing table with a resolution of 0.003 inch and a repeatability of 0.009 inch.

It should be clearly noted that, although the test results show that the sampled 1:100,000 data meets National Map Accuracy Standards for the 1:100,000 scale, the data do not show that the 1:100,000 maps meet National Map Accuracy Standards for the 1:24,000 scale. Although the use of the digital 1:100,000 data may be acceptable at larger scales for applications such as creating FIRM base mapping, the data do not meet the cartographic tests required to be considered an accurate base map for all applications at scales of 1:24,000 and larger.

In creating a FIRM, many different sources of data are used to estimate the boundaries of floodplains and floodways. Plotting the results of hydraulic models onto the FIRM base maps includes engineering judgment and estimation. The most critical of these boundaries is the floodway line. The floodway boundary marks a drastic change in the restrictiveness of NFIP floodplain management criteria. Floodway areas are, for most practical purposes, no-build zones. Because of the importance of this boundary, FIA's most precise criterion for mapping apply to plotting of the floodway boundary. This criterion states that "The floodway widths shown at cross-section locations should agree with values shown on the Floodway Data Table in the Flood Insurance Study report within a maximum tolerance of five percent of the FIRM scale"

(13). Floodplain boundaries are required to be "... consistent with the flood elevations shown on profiles and contour lines and other topographic information shown on work maps" (Ibid,1-8).

In order to meet FIRM base map accuracy standards, 90 percent of the road intersections must be within 0.05 of the base map scale of their true location. Thus, if 1:24,000 base maps are used, intersections must be within 100 feet of their true locations 90 percent of the time. In order to use the cell sampling technique described, confidence limits must be placed on the results to insure that they are sufficiently probable to meet the FIRM base map accuracy requirements. These accuracy requirements do not explicitly state the confidence interval which must be used. Therefore, following standard statistical practice, we interpret these requirements as implying a confidence interval of 95 percent.

In order to place a 95 percent confidence band around the positional accuracy results, we need to know the underlying probability distribution for the statistical distributions describing the roadway intersection distance error on the 1:100,000 maps. The calculated statistical distributions of this error for the two 1:24,000 maps used in the present study are given in Appendix B of The Application of Geographic Information Systems Technology to the National Flood Insurance Program (3). An examination of these distributions and the raw data indicates that the underlying probability distributions are not Gaussian probability distributions. Rather, they appear to be close to a Rayleigh distribution or a somewhat generalized form of the Rayleigh distribution. Unfortunately, the Rayleigh distribution does not have readily accessible tables of confidence intervals for the mean and standard distribution analogous to the Student T and Chi squared distributions for Gaussian distributions. Such tables are needed to estimate the positional accuracy of the 1:100,000 maps at the 95 percent confidence interval. Therefore, such tables have to be worked up using standard statistical techniques.

Once Student T- and Chi squared-like distributions have been worked up for the Rayleigh and generalized Rayleigh distributions, then 95 percent confidence bands can be placed on the results of the present study or any other similar study (14). As long as the 90 percent criterion is within the 95 percent confidence interval, then the results from the 1:100,000 map and hence, digital data base, would be useable for digital representation of FIRMs in the area of interest. Further work needs to be done to validate the approach suggested above before it can be used operationally.

The second major area of concern to be evaluated is the completeness of detail on the 1:100,000 data. To assess problems that might be associated with this concern, each grid cell sampled in the test of road intersection locations, plus an additional twenty grid cells identified at random for each of the 1:24,000 maps tested, were studied to detect any features present in the 1:24,000 data but not included in the 1:100,000 digital data set. The number of features not recorded in each grid cell and the total length of these features were recorded.

The test results showed that, on the average, less than one cell in ten is missing road features. The number of road features missing from a sampled cell varied between one and two, with a total length of approximately 750 feet. Based on the present hardcopy FIRM production requirements and the ability of digital road mapping to be readily updated, this level of missing elements does not present a difficulty to the use of the USGS 1:100,000 data as the base map source for FIRMs.

Some sampled grids contained data on the 1:100,000 data that were lacking from the 1:24,000 data, reflecting the more recent compilation of the 1:100,000 mapping. The degree to which 1:100,000 maps contained information not portrayed on the 1:24,000 maps was not quantified as part of this report.

The third problem involves line geometry. There is no good quantitative test of line geometry quality. The assessment of the quality of line geometry is therefore subjective and dependent on the needs of the map users and the relative ability of the map user to understand and interpret spatial data.

Whether or not these types of line work can serve as a base map for FIRMs depends in large measure on the application and the user. The 1:100,000 digital data set lacks road and place names, is in the Digital Line Graph (DLG) format with single line representation of road features, and, as has been discussed, may not represent smooth curves well at larger scales. To users unfamiliar with maps or lacking information on the area that is being studied, these problems can be significant enough to preclude any usefulness of a FIRM developed by using a raw 1:100,000 data set as the base map.

These problems can be overcome. For example, names can be added to either the digital file or to the hardcopy map output in the same manner that names are currently placed on FIRMs. DLG files can be edited to include more points and thereby more faithfully represent curving features. The single-line geometry can be changed to double-line road fonts when the data are output through computer mapping systems.

Overcoming the problems associated with 1:100,000 DLG line geometry breakdown at large scales is possible. The activities that must take place to perform this task will require interactive editing of the digital files. Costs for this type of activity, which require skilled labor and computer connection charges, are high. In general, it will be desirable to avoid this type of effort whenever possible and whenever more efficient alternatives for base mapping to suit the required application are available.

7. CONCLUSIONS

Sources of digital data are available to serve as base maps for digital FIRMs. The most detailed data are a result of community mapping efforts, which at present have only been completed for a few areas of the country. However, the TIGER files developed by the Census, and the

1:100,000-scale digital data of the USGS provide relatively detailed base map information for all areas of the country.

Portions of two 1:100,000 data were evaluated by FEMA as possible sources of FIRM base mapping. Results from testing the horizontal positioning of road features on the completeness of the 1:100,000 data indicate they could serve as base maps for digital FIRMs. However, the 1:100,000 digital files do not contain road and place names, roads are represented by single-line graphics, and the geometry of curves tends to become angular when the data are used at flood hazard map scales. These problems can be overcome but there are difficulties and costs associated with this process. The application of 1:100,000-scale digital data as base maps for FIRMs may not serve the needs of all users of NFIP map products.

Additionally, because the test data does not apper to represent a Gaussian distribution, further statistical investigation is necessary. This investigation should conclude the applicability of the Student T and Chi square test for a Rayleigh distribution and, therefore, derive a methodology for evaluating the 1:100,000-scale data set for the end user.

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A METHODOLOGY FOR RELATING REGIONS OF CORROSIVE GROUND WATER TO HYDROGEOLOGIC VARIABLES IN THE NEW JERSEY COASTAL PLAIN

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1. INTRODUCTION

1.1 Background

The U.S. Environmental Protection Agency has estimated that 42 million people in the United States may be exposed to elevated concentrations of lead in their drinking water because of corroding plumbing materials (Levin, 1986). Corrosive waters may leach lead, not only from lead pipe, but from the lead/tin solder used to join copper plumbing. Corrosive soil water and shallow ground water also may be responsible for the disintegration of underground storage tanks (U.S. Environmental Protection Agency, 1987). Toxic materials have been released from such tanks into surface and ground water, and the potential for continuing contamination exists. Thus, the spatial distribution of corrosive ground water is a significant health concern.

Corrosive waters frequently are acidic. Other chemical characteristics commonly associated with acidic, corrosive waters are low hardness and low alkalinity. Elevated concentrations of chloride and sulfate in water also may contribute to its corrosive character.

If significant relations between corrosive ground water and hydrogeologic variables could be demonstrated for a given area, then the potential would exist for prediction of other, similar areas of corrosive ground water, based on readily available hydrogeologic data. To study these relations, water-quality data for more than 300 wells that tap the Kirkwood-Cohansey aquifer system in the New Jersey Coastal Plain were examined. It was determined that 164 of these wells, located in an area comprising parts of Ocean and Burlington Counties, were relatively free of changes in ground-water corrosiveness with respect to well-screen depth. Therefore, corrosion-index maps, based on chemical constituents that showed

negligible change with depth, could be expected to represent ground-water corrosiveness in both shallow and deep wells.

1.2 Purpose and Scope

This paper describes (1) the methods used in a study undertaken to map areas of corrosive ground water in the New Jersey Coastal Plain, and (2) the hydrogeologic variables that exert a control on ground-water chemistry and, thus, on the corrosiveness of the ground water. These variables include land cover, soils, geology, and ground-water flow patterns.

Corrosion indices (mathematical formulations based on water chemistry) were calculated for water from 164 wells by using water-quality data from the National Water Data Storage and Retrieval System (WATSTORE). Areas of corrosive ground water were identified on the basis of the calculated index values. Maps of the index values then were compared with maps of hydrogeologic variables such as soils, geology, and other surficial features. Finally, overlay and intersection techniques, using geographic information system (GIS) software, were used to determine the relations between corrosive ground water and hydrogeologic features.

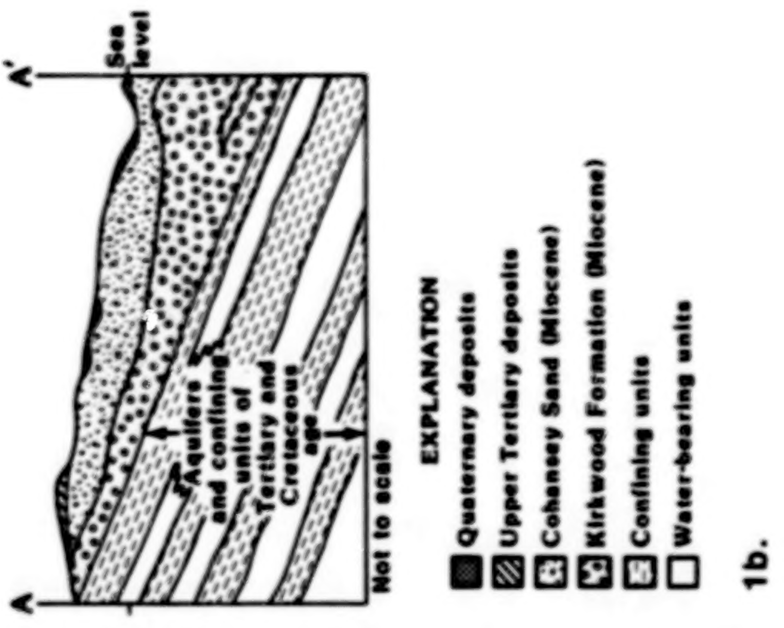
1.3 The Study Area

The study area is contained within the Coastal Plain of southern New Jersey (fig. 1a), and is bounded to the east by the Atlantic Ocean and to the northwest by an outcrop of the western edge of the Miocene Kirkwood Formation and overlying Cohansey Sand. The study area includes Ocean County and the eastern part of Burlington County. Only the ground water from the unconfined Kirkwood-Cohansey aquifer system is considered in this study.

2. HYDROGEOLOGIC SETTING OF THE STUDY AREA

2.1 Topographic and Vegetational Features

The Atlantic Coastal Plain physiographic province, in which the study area is located, is a region of low relief and gently sloping hills. The New Jersey Pine Barrens covers most of the study area. Upland areas are dominated by several species of pine and oak; dwarf pitch



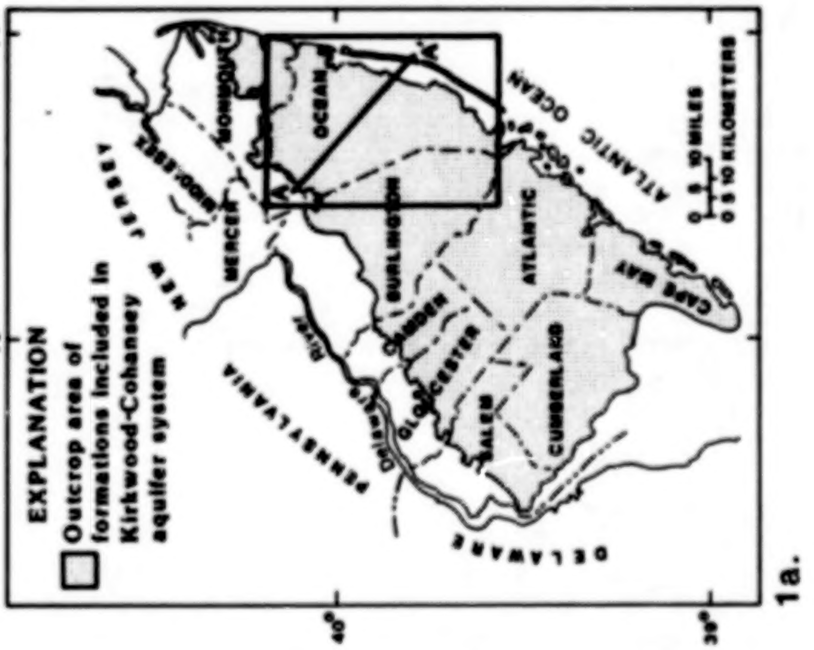


Figure 1a. Map of southern New Jersey, showing outcrop area of principal formations of the Kirkwood-Cohansey aquifer system. Dashed lines show state and county boundaries; heavy solid line shows study area. A-A' gives location of hydrogeologic section in fig. 1b.

Figure 1b. Generalized hydrogeologic section of the study area.

pine occurs in an upland area called the Pine Plains. Lowland areas contain both cedar and deciduous forest swamps.

2.2 Soils of the Study Area

The soils of the study area typically are sands or sandy loams that are very strongly to extremely acidic and have low fertility (Markley, 1979). Soils in upland areas tend to be well to excessively drained Lowland soils, although sandy, generally are poorly drained, and tend to contain a larger percentage of organic material than do upland soils.

2.3 Geology of the Study Area

The Cohansey Sand and Kirkwood Formation, both of Miocene age, are the uppermost of the extensive unconsolidated Coastal Plain sediments in New Jersey (fig. 1b). The lithology of the Cohansey Sand, although variable, is dominated by yellow, limonitic, poorly sorted quartz sand with clay lenses and minor beds of silty and clayey sand present (Rhodehamel, 1979a). The Kirkwood Formation, which underlies the Cohansey Sand, is composed largely of thick beds of micaceous, very fine quartz sand that interfinger with beds of carbonaceous clayey silt (Owens and Sohl, 1969). Thick interbedded clay beds occur near the coastline (Zapecza, 1984). In the study area, the Miocene Beacon Hill Gravel locally forms a veneer over the Cohansey Sand (Rhodehamel, 1979a). Gravelly Quaternary deposits can be found in the south-central part of the study area, and in coastal and estuarine areas.

2.4 Hydrology of the Kirkwood-Cohansey Aquifer System

The Kirkwood-Cohansey aquifer system underlies approximately 3,000 square miles of the New Jersey Coastal Plain. Within the study area, the Kirkwood-Cohansey aquifer system is primarily a water-table aquifer, and recharge is principally through precipitation. Although most recharge enters shallow, local flow systems that discharge to nearby streams, some recharge in upland areas enters deeper flow systems. Recharge areas for the deeper flow systems are in the west-central and northern parts of the study area. The discharge areas are along the coast in the southwestern part of the study area, and scattered along the outcrop area of the Kirkwood Formation and Cohansey Sand (Martin, 1987). Flow patterns within the lower part of the system are relatively local and similar to those in the upper part of the system (M. Martin, U.S. Geological Survey, written commun., 1987).

2.5 Ground-water Chemistry of the Study Area

Ground water in the unconfined Kirkwood-Cohansey aquifer system tends to be acidic. In the study area, the median pH value is 5.4 with a range of 4.3 to 9.1. The ground water in the study area tends to be soft, with a median hardness of 6.0 milligrams per liter as equivalent calcium carbonate, and alkalinity concentrations are low, with a median of 4.0 milligrams per liter as equivalent calcium carbonate. Where nests of wells were sampled, the chemistry indicates that ground water typically maintains its general character over depths down to about 270 feet. Similar ground-water chemistry at different depths suggests that the local flow patterns extend throughout the entire thickness of the Kirkwood-Cohansey unconfined aquifer system. The aquifer material is highly permeable (Rhodehamel, 1979b, p. 153), and ground water recharges and discharges locally. As a result, ground-water chemistry remains relatively constant along flow paths. Hardness and alkalinity concentrations and pH all increase in coastal areas. Sulfate and chloride concentrations are higher in coastal areas than in the inland region of the Coastal Plain.

3. METHODS

3.1 Preparation of Corrosion Index Maps

Two corrosion indices, the Aggressive Index (AI) and Larson Index (LI), were calculated for more than 300 wells in the Kirkwood-Cohansey aquifer system; 164 of these are within the boundaries of the study area. The AI uses pH, alkalinity, and hardness values:

$$AI = pH + \log_{10}(\text{Alkalinity} \times \text{Hardness}),$$

where alkalinity and hardness are expressed as milligrams per liter equivalents of calcium carbonate. Values of AI greater than 12 indicate noncorrosive water, values of 10 to 12 indicate moderately corrosive water, and values less than 10 indicate severely corrosive water. The LI, which is a ratio between corrosion-enhancing anions and the corrosion-inhibiting alkalinity, has the form:

$$LI = (\text{Chloride} + \text{Sulfate}) / \text{Alkalinity},$$

where all constituents are expressed as milligrams per liter of equivalent calcium carbonate. An LI value that exceeds 0.5 indicates the potential for corrosion.

The AI values for the study area were plotted on a map and hand-contoured, by using a fifth-order trend surface as a guide. The resulting contours were digitized and used to create polygons (a GIS polygon coverage), where each polygon represents a range on the Aggressive Index. An identical operation was performed on LI values. The polygon coverages for the two maps (figs. 2 and 3) were then intersected and a third map, a two-variable choropleth, was produced.

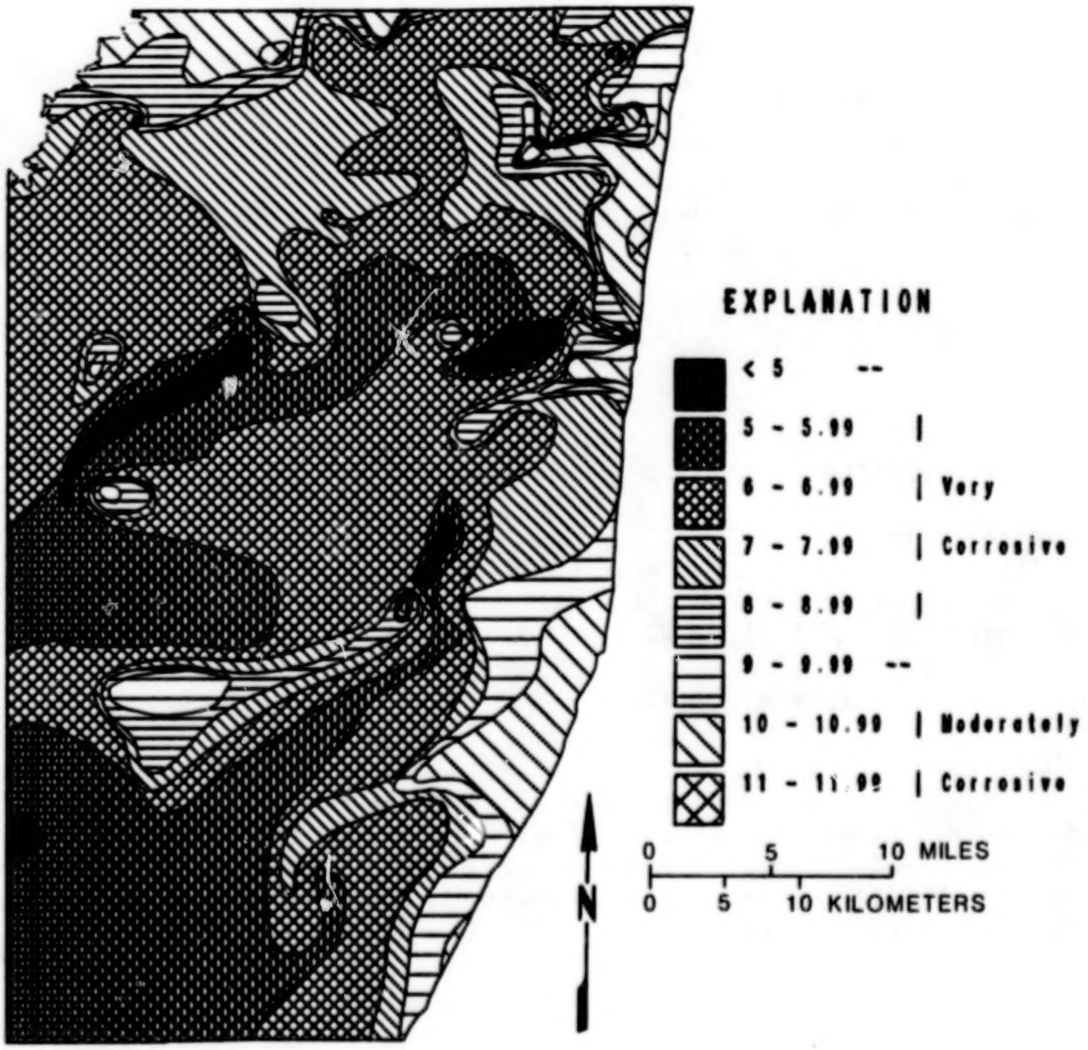


Figure 2. Preliminary map showing Aggressive Index values. This map is based on currently available (1960 through 1986) water-quality data.

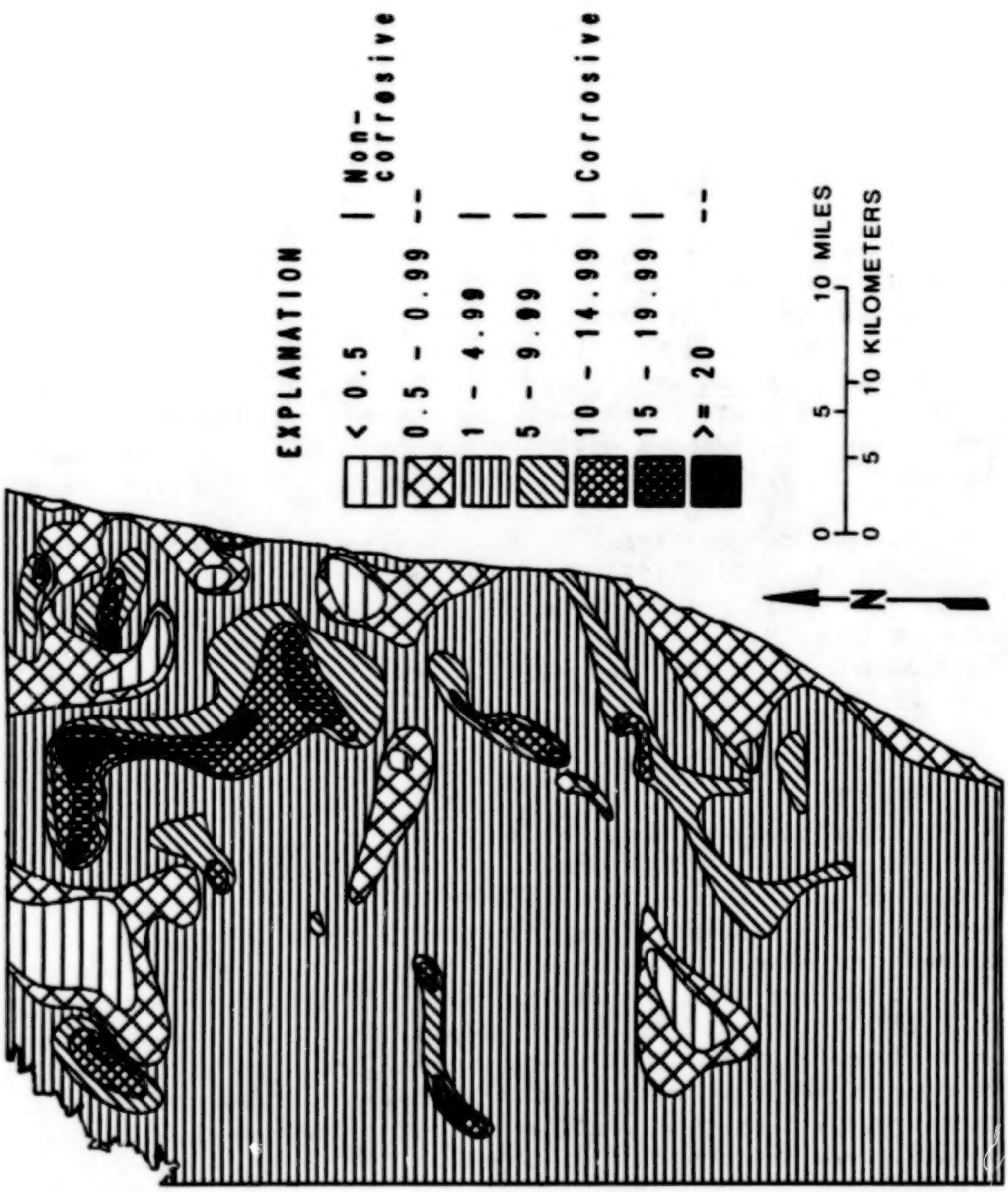


Figure 3. Preliminary map showing Larson Index values. This map is based on currently available (1960 through 1986) water-quality data.

To create the third map, two different hues were used, one for each set of index values. The intensity of each hue varied with the magnitude of the index value. Overprinting of the two hues resulted in the delineation of a number of areas in which both index values predicted highly corrosive water. Because the indices are calculated on different sets of chemical parameters, the third map gives a more complete representation of corrosion potential than is available on

either map considered separately. The choropleth map is meaningful only if presented in color and, therefore, is not reproduced here.

3.2 Hydrogeologic Variables

Polygon coverages were created from readily available data for several hydrogeologic variables (land cover, soils, and surficial geology) that were considered likely to influence shallow ground-water chemistry in the New Jersey Coastal Plain. A coverage of surficial geology was created by digitizing outlines of outcrop areas from New Jersey State Atlas maps, at a scale of 1:63,360. Soils coverage was created by digitizing generalized soils maps (map scale 1:253,440) for Burlington, Atlantic, and Ocean Counties (Markley, 1971; Johnson, 1978; Hole and Smith, 1980). The land-cover/land-use coverages were derived from the U.S. Geological Survey National Mapping Division GIRAS 1972 land-use/land-cover digital data. A generalized elevation contour map was created from spot elevation data from the U.S. Geological Survey's Ground Water Site Inventory (GWSI) data base, using the Triangulated Irregular Network (TIN) option of the GIS software.

3.3 Superposition and Reselection of Coverages

In order to explore relations between corrosion-index values and hydrogeologic variables, frequency diagrams and a series of overlay maps were prepared. A frequency diagram of cells of land cover for different classes of AI ranges in the study area is shown in figure 4. This diagram indicates that the greatest frequency of land cover in the AI range of 5.0 to 7.0 was forest land. Spatial relations between hydrogeologic variables and corrosion-index value were detected by overlaying elevation contours, land-cover data, generalized soils, and surficial geology on the AI contour map.

In order to present simply and graphically the spatial patterns that exist within the study area, ranges of index values, individual soil associations, and geologic units were extracted (reselected) from the existing data sets. By use of the reselected data, maps were created for pattern comparison (figs. 5a, 5b, 5c).

Coverages also were superposed to prepare a data matrix. On the basis of the resolution of the maps used in the study, the need for a data matrix of manageable size, and the necessity of assessing any effects of auto-correlation, a 1,000-square-meter grid was chosen.

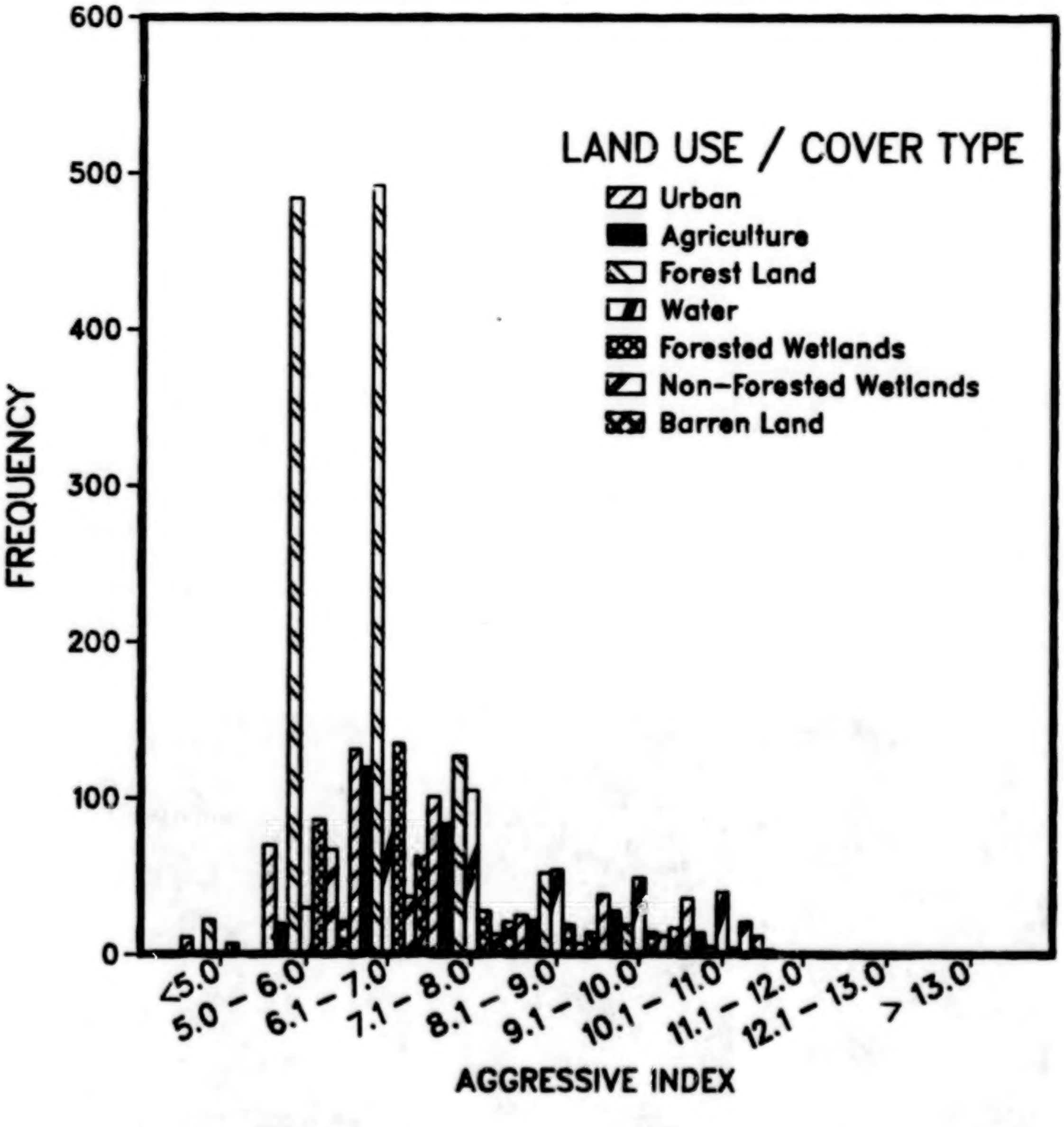


Figure 4. Frequency diagram showing land use/cover polygons within Aggressive Index class.

The grid (67 rows x 45 columns) was overlain on the index value and elevation contours, and index values interpolated at each grid cell. The same grid was superposed on the discrete data sets for soils, geology, and land cover. Each discrete data class was assigned an identifying number. The data class that occupied the largest area within each cell of the grid was chosen to represent that cell. A data matrix was constructed, and exploratory statistical analyses (employing a general linear model) were used to determine if the hydrogeologic variables considered might predict ground-water

corrosion potential. A flow chart, representing the steps taken in the study, may be seen in Figure 6.

4. RELATIONS AMONG CORROSIVE WATER AND HYDROGEOLOGIC VARIABLES

4.1 Areal and Vertical Distribution of Corrosive Ground Water

On the basis of the calculated AI values, ground water in the Kirkwood-Cohansey aquifer system generally is characterized as either strongly corrosive or moderately corrosive. AI and LI values both demonstrate the presence of relatively less corrosive water along the New Jersey coast. The water in some coastal wells is more saline than water from inland wells. But elevated alkalinity concentrations and pH values in the coastal well water offset the effect of increased hardness and chloride concentrations. This is reflected in higher AI values and lower LI values than were calculated for inland wells.

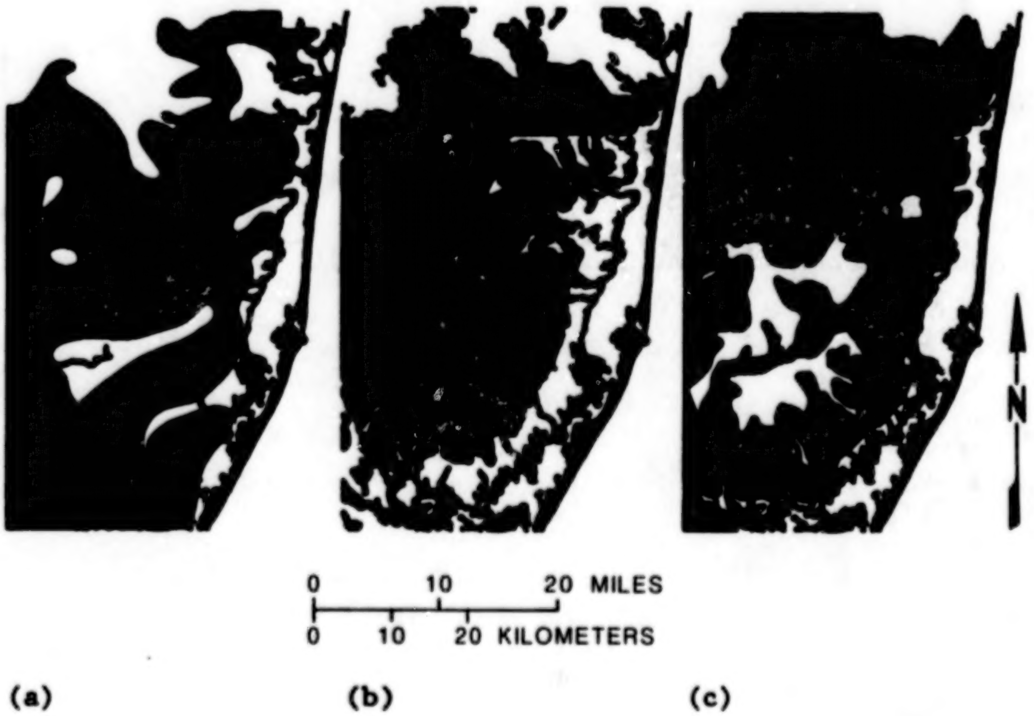


Figure 5. Maps with dark areas showing (a) Aggressive Index values less than 7.1; (b) soils associations which include the most highly acidic soil series; and (c) outcrop area of the Cohansey Sand. Horizontal discontinuity in Cohansey Sand is due to discontinuous data on separate maps.

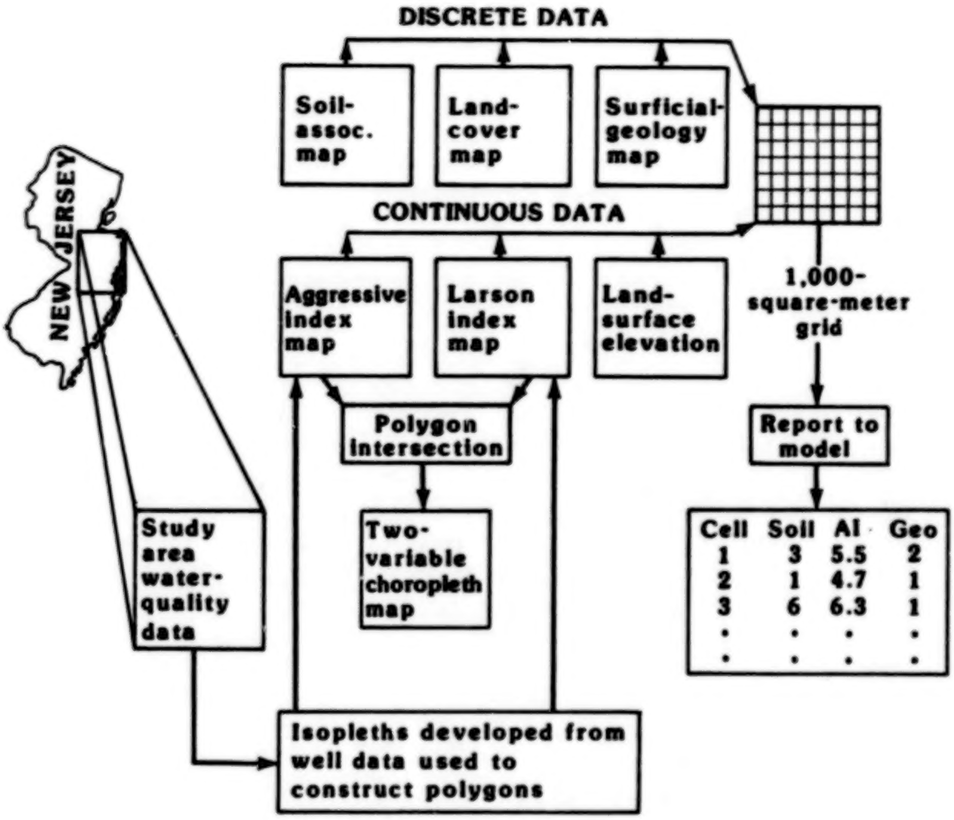


Figure 6. Flow chart showing steps in development of study.

Although AI values were found to be correlated with well depth for the Coastal Plain as a whole, this was not the case for the study area. On the basis of the available water-quality data for the study area, a rank correlation coefficient of 0.098 and a t-ratio of 1.25 indicate that there is no statistically significant change in AI values with depth. The LI values decrease slightly with depth in the study area because sulfate concentrations tend to decrease slightly with increased depth of well screen. Therefore, the contour map of LI values (fig. 3) is a less accurate representation of ground-water corrosion potential in deep and shallow wells than is the map of AI values, as AI values are not correlated significantly with depth of well screen.

4.2 Land Cover and Soils

Areas in which the calculated indices indicate the most severely corrosive ground water underlie strongly acidic soils, both in upland areas and in wetlands. The land cover in these areas consists mostly

of forests and wetlands. A zone of moderately corrosive ground water in the center of the study area underlies part of the upland recharge area and is coincident with a unique upland soil association and Pine Plains vegetation (fig. 5).

4.3 Geology

In the interior part of the study area, strongly corrosive ground water is indicated in areas where the Cohansey Sand crops out. Deep wells in the central part of the study area that penetrate the Cohansey Sand into the underlying Kirkwood Formation also yield corrosive water with AI values that sometimes indicate a slight increase in corrosivity with depth. In the northern and western part of the study area, AI values show that moderately corrosive ground water occurs where the Cohansey Sand is thin or absent and the underlying Kirkwood Formation is exposed. The zone of moderately corrosive water that coincides with the Pine Plains also is associated with outcrops of Quaternary gravels.

5. HYDROGEOLOGIC VARIABLES AS PREDICTORS OF INDEX VALUE

Exploratory statistical analyses, using a general linear model and testing for main effects and crossed effects, indicate that, in the absence of flow data, both soils and geology are significant predictors (at the 0.05 level) of index value. Land cover also appears to be related to index value, but in combination with soils or geology.

6. SUMMARY AND CONCLUSIONS

Aggressive and Larson Index values were calculated for 164 wells in the Kirkwood-Cohansey aquifer system. Contour maps of the corrosion index values were prepared for the study area, and various hydrogeologic variables were superposed on the index values. Relations between areas of corrosive ground water and soils, geology, wetlands, forests, and elevation thus could be demonstrated graphically. A data matrix was prepared, and exploratory statistical analysis was performed. Preliminary results, which did not consider ground-water flow patterns, indicate a predictive relation between index values, soils, and geology. Land cover also appears to be related to index values, but in combination with soils and geology.

Areas of the most corrosive ground water tended to be associated with outcrop areas of the Cohansey Sand, acidic soils, and with forests and freshwater wetlands. The least corrosive ground water was found in areas where the Kirkwood Formation crops out, along the coast, and in the upland area known as the Pine Plains. The graphical method described has shown that consistent relations between ground-water chemistry, as defined by the indices, and hydrogeologic variables can be demonstrated. Ground-water flow patterns and hydraulic conductivity, as predictor variables, also will be explored in the future. The relations that can be demonstrated may be useful in predicting the corrosive potential of ground water in areas where water-quality data are sparse or lacking.

7. ACKNOWLEDGEMENTS

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GEOGRAPHIC CRITERIA FOR THE SITING OF LOW-LEVEL WASTE DISPOSAL SITES

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A. INTRODUCTION

The purpose of this paper is to provide geographic siting criteria on screening areas in order to identify sites for near-surface disposal of low-level radioactive waste (LLW)[1]. These geographic siting criteria include population distribution, land use, natural resources, geomorphology, and other spatially oriented factors.

The paper provides a detailed step-by-step process that the LLW disposal site licensee must go through during the site selection process to meet the Federal Code Requirements (10 CFR Part 61). Specific guidance is provided on how the licensee should proceed through the site selection process. This guidance includes first investigating published reports and maps from the USGS and State geological agencies, local plans and government ordinances, etc. as well as high-level aerial photographs. Investigation of low-level photographs and limited on-site studies occurs in the later phases of the site selection process. The net result of the site selection process should be locating several sites which should meet the requirements of 10 CFR Part 61.50 subject to the final detailed site charaterization process.

B. DISCUSSION

The geographic and other technical site suitability requirements for near-surface LLW disposal are presented in paragraph 61.50(a) of 10 CFR Part 61 (see Appendix A).

[1] This paper is based upon the geographic aspects included in a draft regulatory guide entitled..."Guidance for Selecting Sites for Near-Surface Disposal of Low-Level Radioactive Waste" published by the US Nuclear Regulatory Commission in March 1987.

These requirements address specific conditions that could affect long-term site stability and waste isolation. The site suitability requirements may eliminate from consideration land that has certain unfavorable hydrologic, geologic, land-use, and demographic conditions that could adversely affect the site and its environs.

In evaluating sites for LLW disposal, it is important that a reasonable effort be made to select candidate sites with natural conditions that will maintain radionuclide releases to the general environment as low as is reasonably achievable. The NRC staff considers the long-term contribution of the natural conditions of the site essential in protecting the general population against releases of radioactive material. The effectiveness of other measures such as design features, waste form, waste packaging, and institutional controls is assumed to decrease with time after site closure.

The NRC staff expects that the natural conditions of any proposed near-surface LLW disposal facility will contribute favorably to the isolation of LLW and to the stability of the disposal site after closure. Although it is unrealistic to expect total isolation or site stability in the long term, it is expected that careful selection of a site will limit the potential for radionuclide leaching, provide long pathways to minimize potential radionuclide releases, prevent erosion and inundation of the disposal site to minimize active maintenance, and avoid areas in which land use development activities are occurring. It is expected that the concepts in the technical requirements in § 61.50 will help the applicant meet the performance objectives for effluents (§ 61.41) and long-term stability (§ 61.44). Such careful site selection, along with equally careful consideration of the facility design, operation, and closure requirments of 10 CFR Part 61, will ensure that the overall performance objectives of 10 CFR Part 61 will be met and that the health and safety of the public will be protected.

C. CONSIDERATION FOR SITE SUITABILITY

The following should be considered when screening a region of interest to identify a site for characterization. Evaluation of this information will assist in demonstrating compliance with the site suitability requirements (site characterization).

C.1 Capable of Being Characterized

The ability of the site to provide long-term isolation of waste should be demonstrated by using models and other analyses based on the characteristics of the site. A site that is being considered for LLW disposal must be capable of being analyzed, characterized, and modeled. This suggests identifying the individual components of the site, identifying the physical characteristics that make each individual component unique, and preparing a general representation of each site component to enable predictions of site performance. Although site characterization is not necessary for screening, there are some general concepts that should be considered to provide reasonable assurance that site characterization can be fulfilled.

Sites that are geologically and hydrologically simple and contain processes that occur at consistent and definable rates are preferred over complex sites. For modeling, input assumptions must be valid (representative) for all site conditions. If a complex site condition is not included in a model, it must be demonstrated that the condition either has no effect on site performance or can be accounted for by using a conservative value parameter.

C.2 Population Distribution and Land Use

The candidate site should be located in an area of low population density where the potential for future population growth is estimated to be quite limited. The candidate site should be at least 2 kilometers from the residential property limits of the nearest existing urban community.

Applicable State and local land use plans and regulations (including zoning ordinances) should be fully evaluated to be sure that there are no conflicting regulations or conflicting plans for development in the vicinity of the site. Residentially zoned or planned land uses are considered to be conflicting uses and should not exist or be planned within a 2-kilometer radius of the candidate site. In addition, local and State authorities should be consulted for information on planned highway construction in the vicinity of the site to be sure that no

highways are planned that would interfere with the operation of the site. It is also important to determine whether or not there will be adequate access to the site in terms of future highways and land use.

C.3 Natural Resources

Published or open file information on natural resources such as mineral deposits, coal or hydrocarbon deposits, and geothermal energy sources should be evaluated to determine the potential impact on the site if the resources were to be exploited. Generally, areas should be avoided if they contain natural resources in quantities or of such quality that future exploitation could affect waste isolation.

C.4 Site Must Be Well Drained

A 100-year floodplain, coastal high-hazard area, wetland, or areas where flood velocities could cause damage to the disposal facility are not suitable for waste disposal. In general, significant flood inundation and high water velocities can be expected in poorly drained areas, the floodplains of major rivers, and areas situated near hydraulically steep streams or arroyos with large drainage areas. Such areas should be avoided in the siting of LLW facilities.

Additionally, projected land uses (such as urbanization or other factors that increase runoff potential) should be evaluated to determine the effect of such changes on flood levels, flood-water velocities, and the overall impacts of flooding on site stability.

A waste disposal site should not be located in an area where the natural ground slope is steep. Runoff from intense local precipitation may cause damage to the waste disposal unit or to diversion channels constructed to divert overland flow around the site. Intense rainfall could be a determining factor in the stability of the site. Even though the upstream drainage areas may be minimized, steep slopes could produce high water velocities that could be difficult to mitigate.

C.5 Depth to Water Table

Areas with a known or suspected high water table should be avoided. A disposal site should be sufficiently above the water table so that ground-water intrusion, perennial or otherwise, into the waste will not occur. In no case will waste disposal be permitted in the zone of fluctuation of the water table.

Hydrologic analyses should be based on existing open file reports and maps. To determine the depth to the water table, indirect measurements through geophysical techniques may be helpful.

C.6 Ground-Water Discharge

Areas are not suitable for LLW disposal if ground-water discharge features such as springs, seeps, swamps, or bogs are present. The NRC staff prefers long flow paths from the disposal site to the point of ground-water discharge in order to increase the amount of decay of the radionuclides, increase the hydrodynamic dispersion within the aquifer, and increase the likelihood of retardation of reactive radionuclides in the aquifer.

Hydrogeologic analyses can be conducted by reviewing open file reports, maps, and low-level aerial photographs. In addition, site visits during wet seasons may be helpful in identifying ground-water discharges.

C.7 Tectonic and Geomorphic Processes

A candidate site should not be located in an area of known significant tectonic activity. Analysis of known or suspected tectonic activity during the Quaternary period should be conducted to evaluate the likelihood that the site suitability requirements will be met. In addition, a candidate site should not have the potential for significant mass wasting, erosion, slumping, or landsliding.

Tectonic and geomorphic information can be obtained from open file reports and U.S. Geological Survey and State geologic maps and topographic maps. Combining topographic map information with available regional meteorological data should help in the evaluation for mass wasting.

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C.8 Adverse Impacts from Nearby Facilities

A candidate site should not be located near any facilities or activities that could adversely affect the ability of the site to meet the performance objectives of 10 CFR Part 61. In addition, a candidate site should not be located near facilities that could mask the site monitoring program.

State and local land-use plans should be evaluated to determine the potential for future facilities and activities to adversely impact on the proposed disposal facility.

D. SITE SELECTION PROCESS

The generic site selection process outlined below provides guidance on evaluating a region to identify a site that can meet the licensing requirements for near-surface LLW disposal. The site selection process may vary from State to State or compact to compact[2] depending on a variety of factors, such as the distribution of waste generators, population distribution, or geologic conditions. However, the minimum technical requirements of § 61.50 of 10 CFR Part 61 and the environmental requirements of 10 CFR Part 51 apply irrespective of the site selection process employed.

The four-step site selection process presented in this regulatory guide is summarized in Table 1. The site suitability discussion (Section C) is fundamental to this site selection process.

[2] The Low-Level Waste Policy Act of 1980 provides the opportunity for States to form compacts by which a group of States may exclude other States from disposing of LLW within the compact.

D.1 Step 1

For the first step, the applicant should define the region of interest, such as the compact or State in which the LLW site will be located. The purpose of this first step is to eliminate unfavorable areas and identify candidate areas for further consideration. The applicant should conduct a search of all published and open file documents on generalized land use, transportation, and geophysical information on a regional or State-wide level. Recent high to mid-level aerial photographs should be evaluated for recent land-use changes.

Some examples of areas not suitable for LLW disposal include areas that contain steep terrain, surface waters, wetlands, faults or fracture zones, and karst areas. In addition, there should be no major recharge areas at the site. Examples of significant land-use factors that should eliminate areas from further consideration include proximity to population centers or large parcels of committed lands such as active military land, Indian reservations, or National parks and monuments.

An example of a candidate area suitable for further study would be a sparsely populated area that has no apparent geologic limitations, has easy access to an interstate or limited access highway, and is approximately in the center of major LLW generators. Transportation issues that should be evaluated at this preliminary stage include access, distance from waste generators, and impacts to residential developments along potential transportation routes.

D.2 Step 2

The purpose of Step 2 is to evaluate the candidate areas to identify candidate sites. Much of the local geophysical and land-use data can be obtained through Federal, State, and local agencies. Land-use plans, zoning ordinances, U.S. Geological Survey (USGS) and State geological survey reports, and open file data are examples of information sources that may prove useful in developing a list of candidate sites. For example, local land-use documents should indicate

Table 1 Site Selection Process

	MOST GENERALIZED			MOST DETAILED
Category	Step 1 Region of Interest	Step 2 Candidate Areas	Step 3 Candidate Sites	Step 4* Proposed Sites
Study Area	Compact, State, or geographic region.	A homogeneous area. Sites within an area will contain same general environmental characteristics.	Sites that are potentially licensable.	The site for which the applicant is seeking a license.
Criteria To Be Reviewed	General exclusionary data pertaining to health and safety, areas protected by law.	General compact or State criteria, general screening requirements from § 61.50, and Regulatory Guide 4.18.	General review of compact or State criteria, § 61.50, and information in Regulatory Guide 4.18.	Evaluate compact or State criteria, § 61.50, Regulatory Guide 4.18.
Data To Be Reviewed	USGS and State geologic maps, Federal and State regulations, aerial photographs.	USGS and State geologic maps, topographic maps, university research, local government ordinances and surveys, aerial photographs.	USGS and State geologic maps, topographic maps, university research, local government ordinances and surveys, and local utility maps. Actual field observation.	Data collected to this point and collect original data.
Level of Analysis	Reconnaissance-level map reviews, literature and regulation reviews.	Reconnaissance review of local maps, high-level aerial photographs, literature, and regulations.	Reconnaissance information and site visits (surface-water samples, low-level aerial photos, onsite photos, air analysis, windshield surveys, etc.).	Demonstrate fulfillment of site characterization requirements. Prepare environmental report as necessary.
Purpose	Identify candidate areas.	Identify candidate sites.	Identify proposed site for characterization.	Meet site licensing requirements.

*Step 4 involves site characterization.

whether or not development is planned or permitted in candidate areas. USGS and State geologic survey maps and reports often contain detailed information on faults, flood plains, seismic events, and bedrock and soil composition. Also, the reviewer may wish to examine mid- to low-level aerial photographs for recent land-use changes. (See NUREG/CR-2861, "Image Analysis for Facility Siting: A Comparison of Low- and High-Altitude Image Interpretability for Land Use/Land Cover Mapping";[1] NUREG/CR-3247, "Site Characterization Information Using LANDSAT Satellite and Other Remote Sensing Data: Integration of Remote Sensing Data with Geographic Information Systems";[1] and NUREG/CR-3583, "Evaluation of Low-Altitude Remote Sensing Techniques for Obtaining Site Characteristic Information,"[1] for more information concerning remote sensing applications for site selection.)

D.3 Step 3

The purpose of this step is to evaluate the candidate sites in order to identify the proposed site. Since the National Environmental Policy Act of 1969 (NEPA) requires an analysis of alternatives to the proposed action (site), an environmental report that contains an evaluation of the candidate sites must be developed at the site characterization stage. Although a complete environmental report is not required until a license application is submitted (§ 61.10), the NRC staff suggests that the applicant consider each category in Chapter 3 of Regulatory Guide 4.18 during the site screening process. An early awareness of the environmental requirements should provide reasonable assurance that a complete environmental report can be submitted with a license application.

Data collection during this phase of site selection will require reconnaissance reviews and site visits. Soil and surface-water sampling may be conducted. Land-use, transportation, and geophysical data described in the previous steps should be reevaluated. Recent low-level aerial photographs may be useful for further evaluation. These photographs may show land-use and transportation changes and geophysical features (faults, mass wasting, wetlands) that may not be identified on existing maps. The physical inspection may include a low-level aerial or ground survey (windshield survey) of the site and

the surrounding areas. A suggested technique for conducting a site selection analysis after the data are collected is provided in Appendix B. A substantial amount of information can be obtained through meetings with local utility officials to determine the location of community water distribution systems and other utilities. This information may be important in candidate areas where the presence of potable wells may require the installation of a new water distribution system or an extension from an existing system to ensure the availability of adequate potable water. In addition, information on the location of existing and planned electrical distribution systems is also important in planning for adequate cost-effective power at the candidate disposal facility.

At this stage of screening, a title search of the candidate sites should be conducted. Land ownership information is important so that proper authorities and land owners may be contacted concerning planned onsite visits and surveys. Knowledge of site parcel ownership is important because publicly held land may be easier to acquire for public use. Some states lack the power of eminent domain; therefore privately owned lands may not be available unless the owner is willing to sell. However, dedicated park land should not be used unless it can be demonstrated that there would be no significant environmental or community impacts.

D.4 Step 4

The purpose of this step is to evaluate the proposed site to determine whether it is licensable. A licensable site would fulfill the technical requirements of § 61.50, help ensure the performance objectives of Subpart C of 10 CFR Part 61 will be met, and satisfy the requirements of NEPA. A successful screening program will identify a site that can be licensed for near-surface disposal of LLW.

Guidance on implementing Step 4 (site characterization) can be obtained from NUREG-0902, Regulatory Guide 4.18, and NUREG-1199, "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility."

The purpose of the above described site selection process analysis is to eliminate unfavorable areas from further consideration, in an expeditious and cost effective manner. More detailed and costly site characterization studies need only be conducted in areas which meet all of the 10 CFR Part 61 requirement as outlined by this screening process. This site selection process may be further expedited by the application of a geographic information system (GIS) as described in Appendix B.

APPENDIX A

From 10 CFR Part 61, "LICENSING REQUIREMENTS FOR LAND DISPOSAL OF RADIOACTIVE WASTE"

Subpart C—Performance Objectives

§ 61.40 General requirement.

Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in §§ 61.41 through 61.44.

§ 61.41 Protection of the general population from releases of radioactivity.

Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

§ 61.42 Protection of individuals from inadvertent intrusion.

Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

§ 61.43 Protection of individuals during operations.

Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by § 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable.

§ 61.44 Stability of the disposal site after closure.

The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.

Subpart D—Technical Requirements for Land Disposal Facilities

§ 61.50 Disposal site suitability requirements for land disposal.

(a) Disposal site suitability for near-surface disposal.

(1) The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a near-surface disposal facility. The primary emphasis in disposal site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits.

(2) The disposal site shall be capable of being characterized, modeled, analyzed and monitored.

(3) Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of Subpart C of this part.

(4) Areas must be avoided having known natural resources which, if exploited, would result in failure to meet the performance objectives of Subpart C of this part.

(5) The disposal site must be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year flood plain, coastal high-hazard area or wetland, as defined in Executive Order 11988, "Floodplain Management Guidelines."

(6) Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate waste disposal units.

(7) The disposal site must provide sufficient depth to the water table that ground water intrusion, perennial or otherwise, into the waste will not occur. The Commission will consider an exception to this requirement to allow disposal below the water table if it can be conclusively shown that disposal site characteristics will result in molecular diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of Subpart C of this part being met. In no case will waste disposal be permitted in the zone of fluctuation of the water table.

(8) The hydrogeologic unit used for disposal shall not discharge ground water to the surface within the disposal site.

(9) Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts.

(10) Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts.

(11) The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program.

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APPENDIX B

Geographic Information Computer Mapping

In order to expedite the site selection process, it may be desirable to conduct a geographic information system (GIS) analysis of relevant geophysical and land-use data. An effective GIS technique is computer mapping where geophysical, land-use, and demographic factors are encoded to form a data base for analysis. Each factor should be plotted on separate maps that were generated from the same base map. Each map should then be encoded. It is important that the base map (such as USGS 7.5-minute quadrangle maps) have a coordinate grid system (latitude-longitude or UTM grid) so that the encoded data may be referenced and placed into the data base format for computer mapping analysis.

Once the relevant data is encoded and geophysically referenced according to a set of coordinates, site optimization analysis may begin. The primary feature of a computer mapping program is its capability to composite several factor maps to produce a single derivative map. The compositing is done on a cell-by-cell basis summing the factors within each cell. The user assigns a numeric value or "weight" to each of the mapped factors, and each cell accumulates a "score." The score is the result of the sum of the weights in each cell. A user-supplied symbol is applied to each score level, and the composite map is produced on a line printer.

A simplified example of the compositing analysis process is shown in Figure 1. In this example, the system user wants to locate a LLW disposal site in an area free of three factors: shallow bedrock, surface water, and mature trees (1-A).

The relative importance of each factor is represented by a weight that is assigned by the user. In this case, trees have been assigned the greatest importance and shallow bedrock the least (1-C). The seven unique combinations of these factors produce scores from one through seven; each score represents only one combination (1-D). For example, a score of three can only result from the combination of shallow bedrock and streams. The user could assign the greatest importance to bedrock to determine how areas of relative site suitability would change based on altering the importance of each factor.

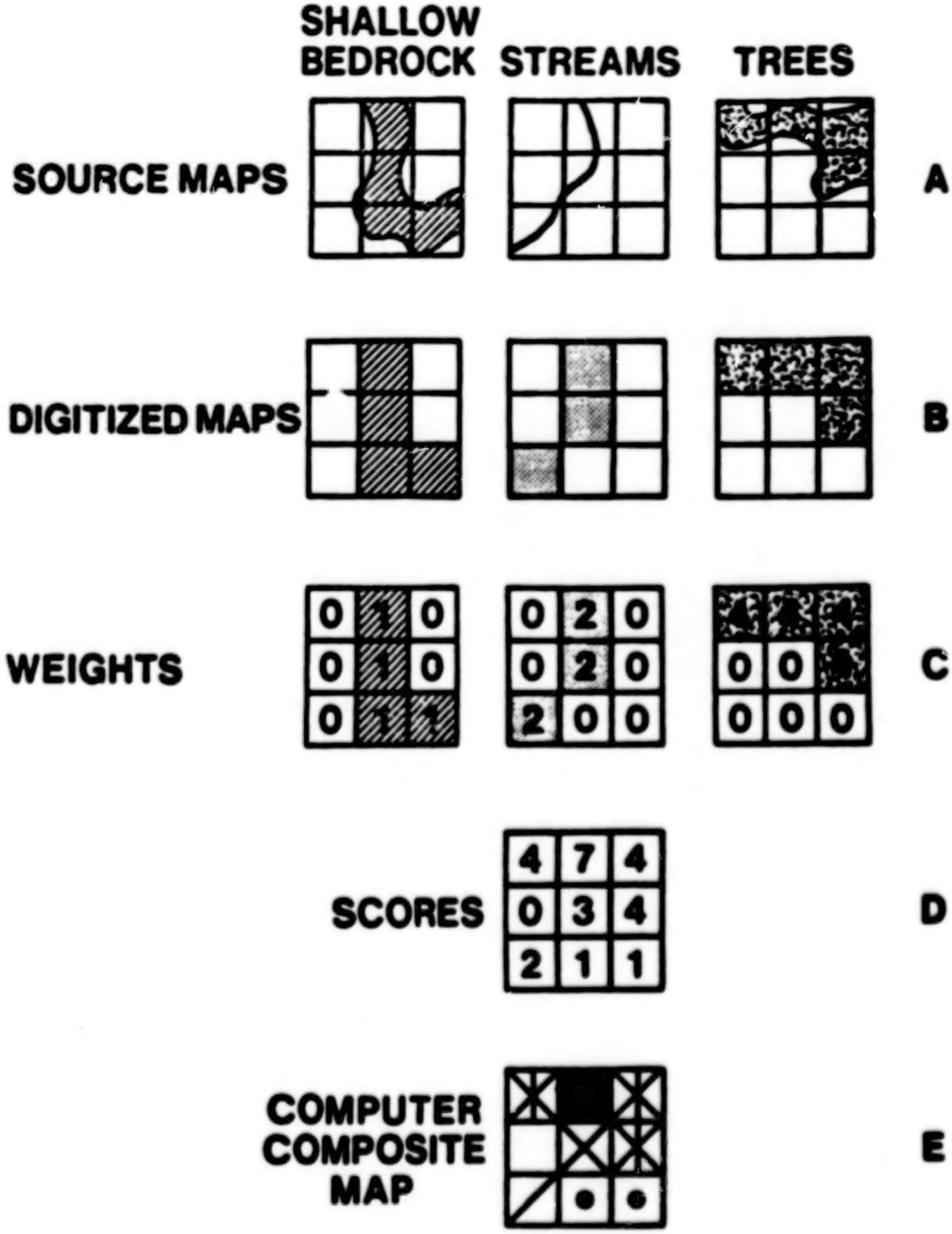

Figure 1 EXAMPLE OF COMPOSITING ANALYSIS

The result of the analysis is a computer-generated composite map that indicates areas most suited for siting LLW disposal facilities based on given weighted factors (1-E). In this case, the user has represented least desirable areas by dark symbols and most desirable areas as white or unpatterned (1-E).

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GROUNDWATER POLLUTION HAZARD ASSESSMENT: A GIS APPROACH

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ABSTRACT

A prototype geographic information system (GIS) has been developed in Harvey County, Kansas to assist water managers in (1) evaluating the complex spatial interrelationships between physical and cultural phenomena that impact groundwater quality, and (2) developing, forecasting, and assessing the outcomes of applying alternative management and regulatory options for groundwater quality protection. The study area includes part of a major unconsolidated aquifer used for both municipal supply and irrigation. Kansas has developed a groundwater quality protection strategy that recommends the development and implementation of aquifer and/or well-field protection plans by all public water systems using groundwater. Methodologies applicable to the planning process have been identified and automated within the GIS. The National Water Well Association's standardized system for evaluating groundwater pollution potential (entitled DRASTIC) has been employed to model groundwater pollution hazard. The GIS has also been used to compute time-related capture zones for public water-supply wells. The capture zone is the aquifer volume from which groundwater flows to reach a pumping well within a given time, although it is usually delineated on an areal map as a capture area. GIS technology has been shown to be an effective tool for managing and protecting groundwater resources. The system has been delivered to the Kansas Department of Health and Environment where it will be used for water resource management.

1. INTRODUCTION

Environmental agencies are increasingly concerned with groundwater quality protection. Approximately 117 million people in the U.S. (50% of the population) employ groundwater for drinking and other domestic uses. About 95 percent of rural households and 34 of the

100 largest U.S. cities rely completely or partially upon groundwater (1).

Groundwater contamination confronts environmental scientists with particularly difficult problems. Detection of contamination and monitoring of water quality, often conducted via observation wells, are difficult and costly. Clean-up of contamination, if possible at all, is often technically complex, expensive and only partially effective (1, 2). Because restoration of groundwater quality is such a formidable task, great emphasis is being placed upon protection of the resource (i.e., prevention of contamination) (3).

Kansas, like many other states, has recently developed a groundwater quality protection strategy (4). Groundwater is an extremely important resource in the state. It supplies approximately 85 percent of Kansas' total water use and is the source of drinking water for some 1.2 million persons. During the process of developing the groundwater quality protection plan, the Kansas Department of Health and Environment (KDHE) recognized that techniques for defining and mapping particularly threatened aquifers and well-fields would have to be identified. A project was initiated to explore potential applications of geographic information systems (GIS) technology in groundwater quality hazard assessment.

2. HARVEY COUNTY PROTOTYPE PROJECT

A prototype geographic information system was established in Harvey County, Kansas to enable water resources managers in state, regional, and county agencies to more effectively address issues pertaining to groundwater and surface water quality protection. Although designed for water resources management, others would find the same GIS useful for applications ranging from urban planning and land appraisal to soil erosion hazard assessment and wildlife habitat evaluation.

The project had four principal objectives:

1. to provide water-resources managers, administrators and policy-makers with a "hands-on" capability to test and evaluate GIS technology in a real-world situation;

2. to build, via system utilization, a group of knowledgeable GIS users;

3. to generate suggestions for system design and software modifications, and for effective application of the system as a decision-making tool; and

4. to provide a mechanism for establishing firm cost-benefit rela-

tionships.

The principal participants in the prototype project include the:

1. University of Kansas Applied Remote Sensing (KARS) Program - responsible for GIS construction, software development, training and technology transfer, and coordination with the Kansas Commission on Applied Remote Sensing (KCARS);

2. Kansas Geological Survey (KGS) - responsible for identifying and accessing data, developing models and algorithms for data analysis pertaining to geohydrology and water quality, and coordination with other Kansas agencies involved in water resources management; and

3. Kansas Department of Health and Environment (KDHE) - responsible for identifying and facilitating access to source data, developing conceptual models and algorithms for data analysis pertaining to potential legislation and regulatory functions, and state-federal project coordination.

Other agencies contributing to the project were the U.S. Environmental Protection Agency (EPA) and the U.S. Soil Conservation Service (SCS).

2.1 Project Background and Scope

Approximately eight percent of those Kansas public water supplies which are drawn from groundwater contain concentrations of pollutants which exceed State/Primary drinking-water standards. Such pollution may stem from natural circumstances and/or may be related to agricultural (e.g., pesticide applications), industrial (e.g., from oil-field brines) or municipal (e.g., sewage disposal) sources. The potential exists for additional contamination as man's activities change, become more intense, and cover a greater portion of the area overlying the aquifers. Land-use planning and management of these activities is an important approach to groundwater quality protection, an approach that can be greatly aided through use of GIS technology.

2.2 Study Area

The study area includes all of Harvey County, and those portions of the 7.5-minute U.S. Geological Survey topographic quadrangles that extend from Harvey County into the adjacent easternmost townships of Reno County, and the contiguous northernmost townships of Sedgwick County, Kansas. This 800-square mile region includes a portion of a major aquifer (the Equus Beds) that, in terms of groundwater resour-

ces, probably supplies the largest number of people in Kansas for an area of equivalent size. The water is used for both irrigation and municipal purposes. The well field (public water supply) for the City of Wichita (population 400,000) and a major portion of the Equus Beds Groundwater Management District (EBGMD) are included within the study site. A region of sand dunes lies in the northwestern part of the study area. A section of the alluvial aquifer of the Arkansas River is in the southwest, while limestone aquifers yielding supplies of water adequate for only domestic or stock purposes are in the east. Oil has been produced since the 1930's from the Burrton and other, smaller, oil fields. Oil-field brine has polluted portions of the aquifer around the town of Burrton and in the northwest corner of Harvey County. An Intensive Groundwater Use Control Area (IGUCA) and a Special Water Quality Use Area (SWQUA) have been designated by the Division of Water Resources of the State Board of Agriculture at the request of the EBGMD.

3. SYSTEM DESIGN AND DEVELOPMENT

System design was based upon review of existing literature on groundwater quality protection (5), extensive discussions with KDHE staff and other groundwater specialists, and evaluation of pertinent GIS research (6, 7, 8, 9, 10). In regard to the latter, it was observed that GIS technology has, to date, more often been used to assess existing groundwater contamination problems rather than to forecast potential hazards. Taking into consideration all that we had learned, we developed the prototype GIS specifically to allow us to implement two spatial models. The National Water Well Association's standardized system for evaluating groundwater pollution potential (enticled DRASTIC) was employed to model groundwater pollution hazard. The model incorporates seven factors, each rated and weighted differentially, to produce a numerical index value that can be used to evaluate a site's relative vulnerability to groundwater pollution. The system has also been used to compute time-related capture areas for public water-supply wells. The capture zone is the aquifer zone from which groundwater flows to reach a pumping well within a given time. The prototype system was developed on the ERDAS (Earth Resources Data Analysis System) GIS operating on an IBM PC/AT computer.

3.1 Database Development

All data employed in the GIS were encoded in, or converted to, raster format. A separate file was created for each of the 15 U.S. Geological Survey (USGS) 7.5-minute topographic quadrangles covering the study area. The finest resolution used was a cell having a dimension of 165 feet^2 (0.625 acre). Much of the source data, however, did not warrant use of such a fine raster (Table 1).

TABLE 1

HARVEY COUNTY PROTOTYPE GIS

CHARACTERISTICS OF SOURCE DATA

File	Data Source	Format	Scale	Date of Information
Generalized Well Yields	KGS-USGS	Map M-4A	1:500,000	1967 - Revised 1975
Specific Yield for Source	KDHE	Tabular	NA	Variable[1]
Elevation of Water Table	KGS-USGS	Digital	Variable	1980
Depth to Water	KGS-USGS	Digital (Derived[2])	Variable	1980
Annual Recharge	KGS-USGS	Map	≈1:50,000	1980
Quality (Brine Pollution)	KGS Report	Map	≈1:70,000	1983
Storage Coefficient (Hydraulic Conductivity)	KGS-USGS	Map	≈1:50,000	1980
Public Water Supply Wells	KDHE	Tabular	NA	Variable[3]
Publicly Owned Wastewater Treatment Plants	KDHE	Tabular	NA	Variable[3]
Landfills/Dumps	KDHE	Tabular	NA	Variable[3]
Hazardous Waste Generators, Storage, Disposal Sites	KDHE	Tabular	NA	Variable[3]
Industrial Lagoons	KDHE	Tabular	NA	Variable[3]
Agricultural Feedlots	KDHE	Tabular	NA	Variable[3]
Oil/Gas Fields	KGS	Map M-17	1:500,000	1982
Land Use	USGS/ASCS	Aerial Photography	1:58,000	May 1985
Soil Series	SCS - County Soil Survey	Map	1:20,000	Variable[4]
Elevation	USGS	Digital	1:250,000	1955 - Revised 1966 and 1969
Surface Hydrography	KGS	Digital	1:24,000	Variable[5]
Geology	KGS	Map M-1	1:500,000	1964
Transportation Routes (U.S. Highways/Railways)	KGS	Digital	1:24,000	Variable[5]
Public Land Survey (Township-Range-Section)	KGS	Digital	1:24,000	Variable[5]
County Boundaries	KGS	Digital	1:24,000	Variable[5]
Wichita Water Field Boundary	(Included on Public Wells Map)			
Slope	(Derived from Soils Data)		1:20,000	Variable[4]

1 - Date based on monitored wells.
2 - Derived from contoured points of elevation of land surface and water table at wells.
3 - Date based on issuance of permit.
4 - Harvey County 1969, Reno County 1969, Sedgwick County 1975.
5 - Date based on last revision of quadrangle.
ASCS - Agricultural Stabilization and Conservation Service
KDHE - Kansas Department of Health and Environment
KGS - Kansas Geological Survey
USGS - United States Geological Survey
SCS - United States Soil Conservation Service
NA - Not Applicable

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A wide variety of geographically-referenced data, including both natural (e.g., soils, hydrogeology) and anthropogenic features (e.g., land use), were encoded. These data were obtained from a multitude of sources and existed originally in different formats and scales, as indicated in Table 1. The construction of the databases for the GIS thus involved transformation and transfer of the information to the IBM PC/AT in a form usable by the ERDAS software.

Some data were in tabular format (i.e., certain well locations) or had not yet been mapped (land use). The process of transforming these data into digital spatial information required interpretation of aerial photographs. Other data existed as maps, but at differing scales (recharge, soils, geology, oil/gas fields). Some data were available in a digital format (ground-surface, bedrock, and water-table elevations, and surface hydrography). These data required rectification of the cartographic projection in which they were stored to the reference projection of the GIS. Finally, certain databases were needed for the DRASTIC and capture-zone programs, but did not exist as such (depth to groundwater, saturated thickness of aquifer). These were derived using automated techniques. For example, the file for depth to groundwater was generated by computer subtraction of water-table elevation from ground-surface elevation at observation wells. The results were processed using the SURFACE II program developed by the Kansas Geological Survey to generate contours of depth to groundwater (11). The SURFACE II grid file was then converted into a format acceptable for use in ERDAS.

3.2 Implementation of DRASTIC

The National Water Well Association (NWWA) has developed a standardized system for evaluating groundwater pollution potential using hydrogeologic settings (12). Entitled DRASTIC, the system involves the mapping of hydrogeologic settings and the computation of index values ranking the relative vulnerability of areas to groundwater pollution. Ratings and weights are assigned to seven factors to produce a grand numerical index indicative of groundwater pollution hazard. The selection of the seven factors, and their ratings and weightings, was accomplished by a committee of hydrogeologists working under the auspices of the NWWA. The seven factors used to compute the DRASTIC index are:

Depth to water table;
Recharge (net);
Aquifer media;
Soil media;
Topography (slope);
Impact of the vadose zone; and,
Conductivity (hydraulic) of the aquifer.

The DRASTIC index is determined from the equation:

$$DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw = \text{Pollution Potential}$$

where r is the rating and w is the weight for each factor. Ratings vary from 1 to 10 and determine the relative significance of classes within each factor. For example, fine textured (clayey) soils are less permeable to water than coarse (sandy) soils. Fine textured soils are, therefore, assigned a lower rating than soils with a coarse texture since, all other things being equal, they are less likely than sandy soils to allow infiltration of a pollutant. Weights vary from 1 to 5 and determine the relative importance of the factors with respect to one another. It is interesting to note that the system was not designed for use in a GIS. In fact, initial application was via manual map overlay and computation (13). Our effort was directed toward automation of DRASTIC.

Ratings for each of the factors were assigned to the appropriate data files during digitization or via ERDAS. An interactive computer program was then prepared to calculate the DRASTIC index. The DRASTIC index computed for the Halstead USGS 7.5-minute quadrangle is portrayed in Figure 1.

An area of sand dunes overlying silty clays is present in the northwest portion of the Halstead quadrangle. In some regions of the map, rectangular areas are apparent. These result from the character of the data files used to generate the index values. For example, the best available source data for recharge and hydraulic conductivity has a spatial resolution of 1 mile^2, while the other files have finer resolution, with soils being the most detailed. The rectangularly-shaped areas, therefore, reflect the coarse resolution data. The presence of these artifact shapes should serve to remind map users that the DRASTIC map can only be applied to regional or reconnaissance studies.

Automation of DRASTIC facilitates recomputation of the index to incorporate revised or additional data or to determine the sensitivity of the index to estimated errors in the hydrogeologic data. For example, a geologic map was initially used to identify the materials from which the ratings for the vadose zone were determined. Well logs indicate that silty clays in the vadose zone underlie a region shown as dune sand on the geologic map. The vadose zone material selected to represent this area was then revised to include the relative proportions of sand and silty clay, and the appropriate rating value was determined from the ratings table. This area was recoded in the vadose zone file, and a new map was easily generated by the interactive program prepared to compute DRASTIC indices.

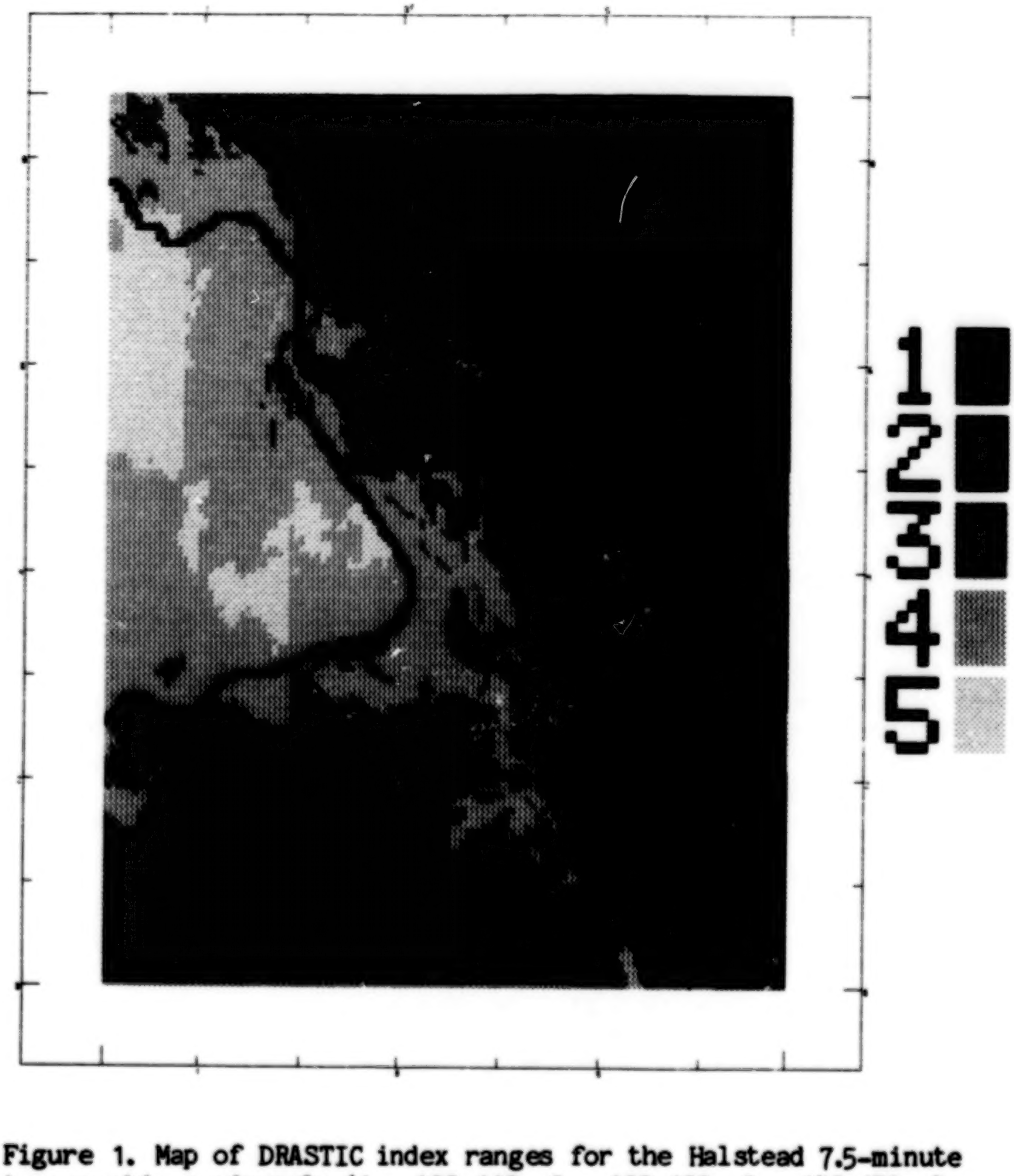

Figure 1. Map of DRASTIC index ranges for the Halstead 7.5-minute topographic quadrangle (1 = 100-119; 2 = 120-139; 3 = 140-159; 4 = 160-179; 5 = 180-199). The lighter the shading, the greater the potential for groundwater pollution.

3.3 Development of Time-Related Capture Zones Model

The Groundwater Quality Protection Strategy being developed in Kansas recommends that public water-supply statutes be amended to require the development and implementation of aquifer and/or well-field protection plans by all public water systems using groundwater. These plans should include an identification of potential sources of pollution within the zone of influence of the well-field and additional upgradient area that could reasonably affect the groundwater source (4).

Previous methods for wellhead zoning have often involved definition of circular capture zones based on a radius defined without consideration of the specific hydrogeologic characteristics of the aquifer. A "time-related capture zone" is the aquifer volume from which groundwater flows to reach a pumping well within a given time capture area, although it is usually delineated on an areal map as a capture area.

The approach we used to determine a capture area involves averaging of the hydrogeologic parameters involved in the capture computation over the area of interest, i.e., generalizing the aquifer to a homogeneous, uniform-flow system. Although we believe further enhancement of the method is desirable, our approximation is still a great improvement over concentric ring zoning.

A time-related capture area within a uniform flow field is an ellipse-like curve. The capture curve changes from a circle around the well in an aquifer with no regional flow to an elliptical shape with increasing eccentricity the greater the regional flow rate. The well is located near the down-gradient focus of an elliptical approximation of the capture curve.

An interactive program was developed to allow computation of individual capture zones (14). The program requires the following information: (1) the latitude and longitude of the northwest corner of the quadrangle area; (2) the average values of the aquifer parameters for the quadrangle (hydraulic conductivity, saturated thickness, porosity, flow direction, and hydraulic gradient); (3) the capture zone time; (4) the number and coordinates of the pumping wells; and, (5) the average pumping rates of the wells. The information may be entered directly by the user or read in from an existing file. Information for this file can be drawn from the data bases in the GIS; aquifer parameters for the desired quadrangle can be computed from the database files using an averaging routine written for the GIS. After the calculation of the capture areas, a rasterization program is invoked to convert the vector results into the ERDAS raster format. ERDAS functions are then used to display the capture zones.

The capture-area boundaries generated for wells in the Wichita well field are superimposed on a land-use map in Figure 2. The map area consists of six 7.5-minute quadrangles. The boundaries were computed for a 50-year capture period. The Wichita well field consists of 52 wells in the Equus Beds aquifer in the southern part of the study area. Each of these wells pumps from about 500 to over 1000 gal/min when operating. An average pumping rate of 1000 gal/min was used for all the wells in computing the boundaries in Figure 2 to show the maximum capture area possible if all wells were operating at this rate.

The present land use occurring within the well-field capture zone is predominantly agriculture. A map of the main surface transportation (potential location of accidental spills) shows that there are no roads with substantial truck traffic that pass through the capture area, but there is a railroad located in the southwest corner of the capture area. A map of potential point-pollution sites digitized for the GIS indicates that there are no waste-disposal facilities, although there are a few feedlots, within the capture area of the well field. A map of water quality showing an area of oil-field brine contamination of the aquifer indicates that the northwest corner of the capture zone just touches the southeast portion of chloride concentration contours above 250 mg/L. The well-field capture boundaries can also be placed over the DRASTIC results to show which portions of the capture areas are most susceptible to contamination.

4. SUMMARY AND CONCLUSIONS

The following significant results have been achieved:

1. A multifaceted digital geographic database has been compiled for Harvey County, Kansas. The data are comprised of information derived from a variety of source materials (tabular, digital, and map). Data were encoded via a number of different mechanisms including:
   (a) direct digitization of maps (e.g., soils);
   (b) geo-referencing and digitization of tabular files (e.g., KDHE files);
   (c) reformatting existing digital data to the ERDAS format (e.g., KGS digital line graphs); and,
   (d) computation of derived variables via use of KGS Surface II software and transferral of results to ERDAS (e.g., depth to groundwater).
2. Two models for groundwater quality hazard assessment have been automated (i.e., DRASTIC and time-related capture zones).
3. Representatives of KDHE, EPA, KGS and SCS have been involved in the project. The interagency, interdisciplinary activity has produced a synergism from which all participants have benefited.

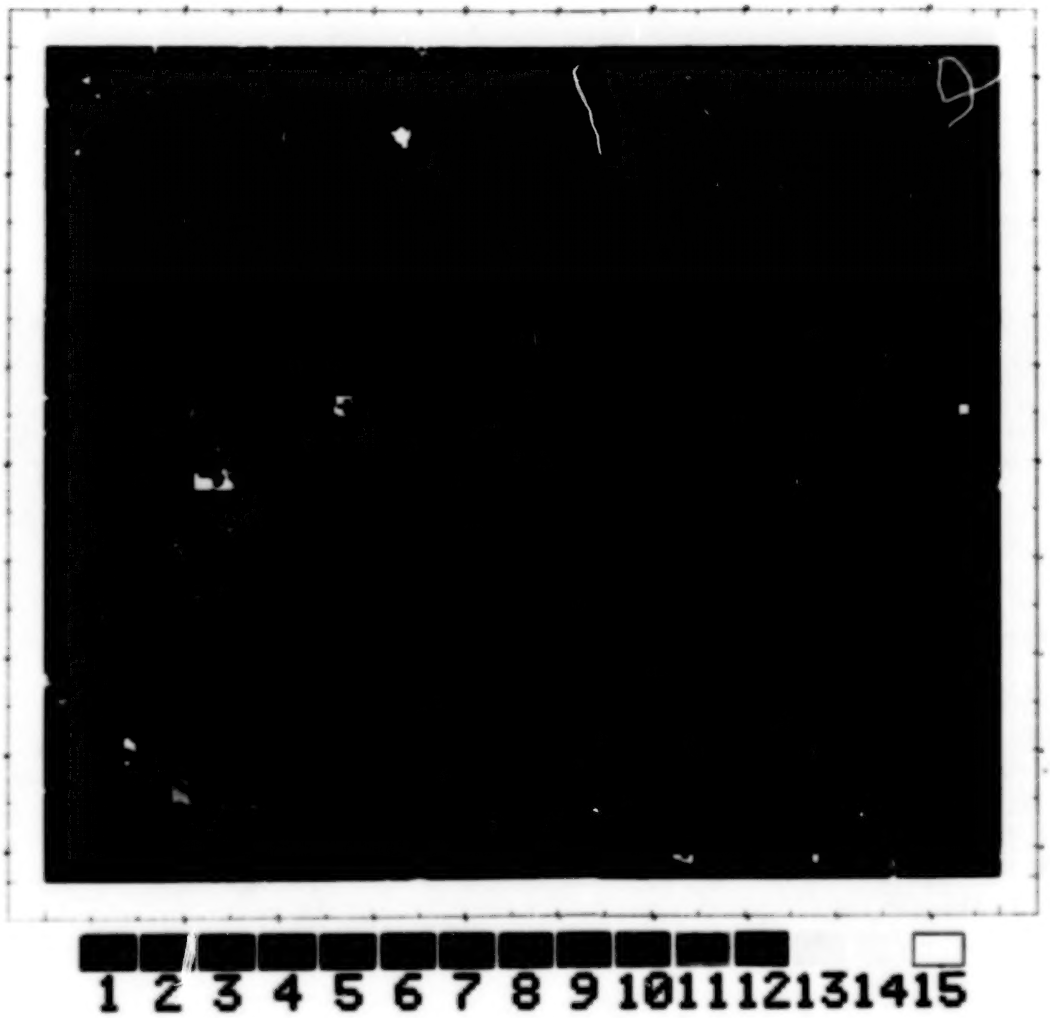

Figure 2. Computer plot of capture-zone boundaries for the Wichita water-well field overlaid on land use. The six 7.5-minute topographic quadrangles comprising the figure area are Burrton, Halstead, Zimmerdale, Patterson, Bentley, and Sedgwick. The legend for land uses is 1: residential; 2: commercial and services; 3: transportation, communication, and utilities; 4: railyards; 5: urban openland; 6: built-up rural; 7: irrigated croplands and pasture; 8: non-irrigated crops and pasture; 9: rangeland; 10: forest; 11: riparian forest; 12: lakes (over 40 acres); 13: stock ponds (under 40 acres); 14: quarries with water; 15: quarries without water.

Our collective efforts to design the GIS and implement analytical models have resulted in opening our eyes to new opportunities and alternatives. We believe these outcomes are harbingers of successful technology transfer.

4. The GIS has been demonstrated for representatives of KDHE, SCS, the Kansas Department of Revenue, the Kansas Water Office, EPA, USGS, the National Water Well Association, the Iowa Geological Survey, the Nebraska Department of Environmental Control, the Missouri Department of Conservation, the Kansas Water Data Committee, and the Kansas Commission on Applied Remote Sensing. These demonstrations have fostered a significantly improved understanding of the nature and value of GIS technology, and have provided valuable feedback regarding improvements which might be made in the prototype system.
5. KDHE personnel have been trained in digital database construction, data manipulation and analysis (using both ERDAS and KGS/KARS developed software). The ERDAS system has been delivered to KDHE for operational use.
6. The project has, in a broader context, also served to help guide Kansas policymakers in making informed decisions regarding future GIS utilization, implementation, integration and institutionalization on a statewide basis.

Acknowledgments

This research was principally funded by a grant from the Kansas Department of Health and Environment. The authors gratefully acknowledge KDHE support. P. Di and H. Zhou, graduate research assistants at the Kansas Geological Survey, prepared and processed some of the data used in ERDAS. G. Plumb and J. Christensen, research assistants at the Kansas Applied Remote Sensing Program, contributed to software development and data entry, respectively.

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THE ENVIRONMENTAL PROTECTION AGENCY'S DIRECT/DELAYED RESPONSE PROJECT: THE ROLE OF A GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT

The Direct/Delayed Response Project (DDRP) examines the question "What is the possible future long-term response of the chemistry of surface waters to continued acidic deposition?". An ARC/INFO* Geographic Information System (GIS) plays a vital role in a variety of analytical procedures and predictive models. Specific GIS-related tasks within the DDRP includes: the characterization of individual watersheds; the analysis and mapping of regional characteristics; the mapping, display, interpolation and contouring of input/output data; the analysis and mapping of other relevant lake and/or stream chemical data; and the display and interpretation of regional or sub-regional variations in adsorptive characteristics of watersheds. These types of GIS-based analyses contribute significantly to all levels of research within the DDRP. The ability to incorporate and analyze tabular and/or mapped data within the GIS allows researchers at the EPA's Environmental Research Laboratory in Corvallis, Oregon to interactively examine and test various hypotheses concerning the long-term response of surface waters to continued acidic deposition.

1. INTRODUCTION

The Environmental Protection Agency's Direct/Delayed Response Project (DDRP) is examining the question "What is the future possible long-term chemical response of surface waters to continued acidic deposition?". The DDRP requires detailed watershed maps of those characteristics important to the effects of acidic deposition. To provide this information, the USEPA contracted with the USDA Soil Conservation Service to map soils, vegetation, geology, and depth-to-

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*Mention of brand names or commercial products does not constitute endorsement or recommendation for use.

bedrock on 145 watersheds in the Northeast and 35 watersheds in the Southern Blue Ridge Province (Figure 1). Land use maps are provided by the EPA Environmental Monitoring and Systems Laboratory in Las Vegas, Nevada.

To evaluate the chemical response of surface waters to continued acidic deposition, the DDRP formulated the following objectives: characterize the variability of soil and other watershed characteristics across the regions; determine which of the soil and watershed characteristics are most strongly related to surface water chemistry; estimate the relative importance of key watershed processes; and classify a sample of watersheds with regard to response to acidic deposition and extrapolate the results from the sample to the regions.

The DDRP is integrating data from the intensively studied DDRP watersheds with data from other sources, including lake chemistry data from the EPA's National Surface Water Survey (NSWS), U.S. Geological Survey runoff maps, dry and/or wet deposition estimates, precipitation and evapotranspiration estimates, existing regional physiographic and land use maps, and 1:250,000 Digital Elevation Models. These data are being used in three levels of DDRP analysis: system description, single factor response time estimates, and dynamic systems models (Table 1).

Table 1. Three Levels of Analysis used within the DDRP.

Level I. System Description:

Statistical description of the variability in soil and other watershed characteristics within and among watersheds, soil types, and geographic regions; evaluation of the input-output balance of sulfate in the NSWS watersheds; and indices of soil water content.

Level II. Single Factor Response Time Estimates:

Time to steady state of sulfur adsorption in soils; time to reduction of soil base saturation to a critical value; time of water travel and residence times in watershed soils; and estimates of mineral weathering rates.

Level III. Dynamic System modeling:

Integration of major processes to predict changes in soil conditions and surface water chemistry over time; sensitivity analysis of model predictions given regional variability in soil and watershed characteristics; and classification of the response time of watersheds included in the soil survey.

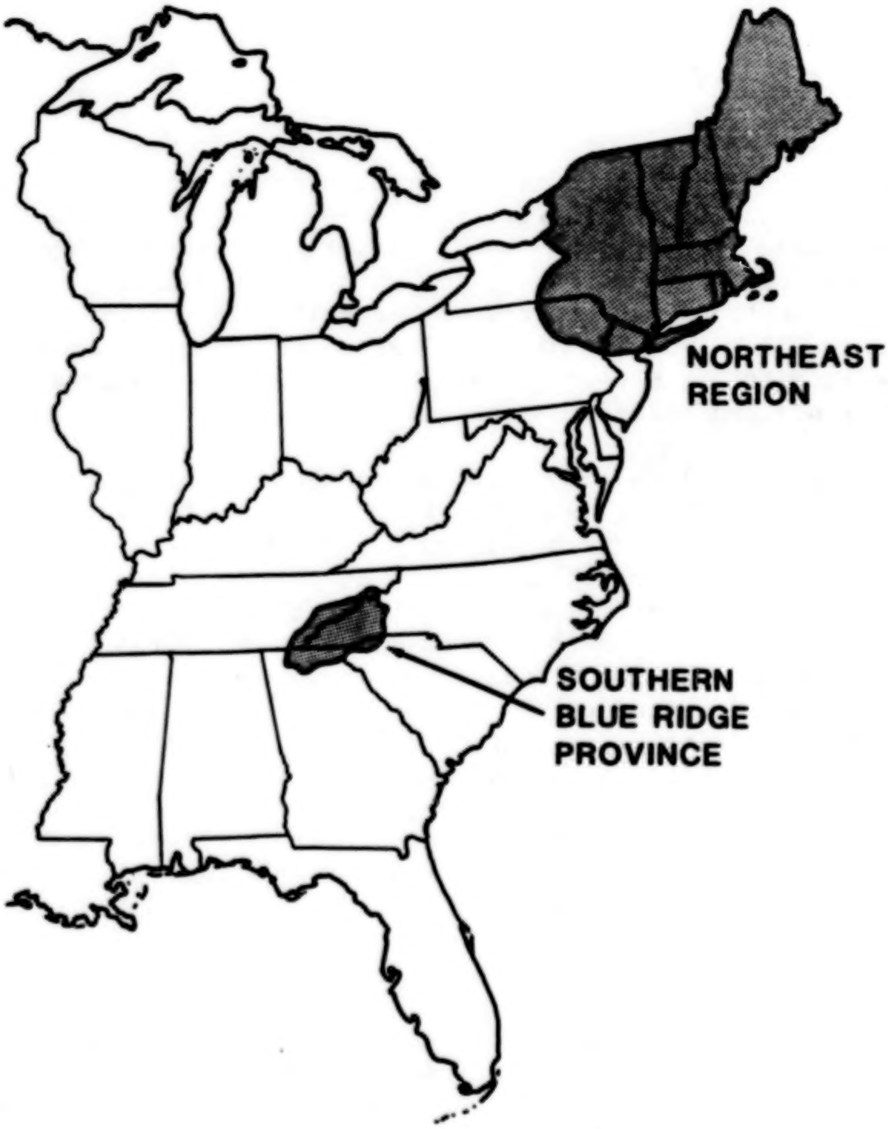

Figure 1. Map of regions of concern for the DDRP.

An ARC/INFO Geographic Information System (GIS) plays an integral role in DDRP data integration and analysis. In particular, the GIS allows researchers to interactively examine and test various hypotheses concerning the response of surface waters to acidic deposition. Specific GIS-related tasks include watershed characterization, spatial representation and analysis, and regionalization and extrapolation of results.

2.WATERSHED CHARACTERIZATION

The influence of key watershed variables on surface water chemistry can be examined by characterizing or displaying the spatial distribution of individual and/or aggregated variables (e.g., soils, soils/vegetation intersection). These spatial characterizations can ultimately be related to surface water chemistry via statistical, graphical, or cartographic techniques. Watershed characterization involves describing individual variables, identifying map units in close proximity to the study lake or stream reach, and aggregating map units within and between layers.

Characterizing spatial relationships among the watershed variables allows researchers to develop and test various hypotheses concerning the effects of individual variables on surface water chemistry (Figure 2a). The watershed variables, particularly soils, that occur closest to the water body might exert the greatest effect on its chemistry. The influence of these proximal land units can be investigated by determining the land area components within certain distances (either longitudinal or elevational) of the lake or stream reach (Figure 2b). Although a single variable (e.g., soil mapping units) might not adequately explain the chemistry of surface waters, particular aggregations or combinations of variables might yield significant results. Aggregated map units, either between or within layers, should also help explain or predict water chemistry (Figure 3).

3.SPATIAL REPRESENTATION AND ANALYSIS

A variety of GIS-based cartographic techniques are used for display and/or interpretation of regional or sub-regional variations in selected parameters. These spatial displays are useful to explain or predict water chemistry across the regions of concern. Both analytical (e.g., interpolation of modeled distributions to points) and descriptive (e.g., depiction of the distribution of sulfate concentrations in sampled water bodies) processes can be incorporated within the analyses. Output options include point location maps, circle maps, contour and/or interpolated maps or datasets, and Thiessen polygon maps.

Point location maps display the location, number, and distribution of important sites within the particular regions. From such maps, researchers can examine the spatial distribution of key research or

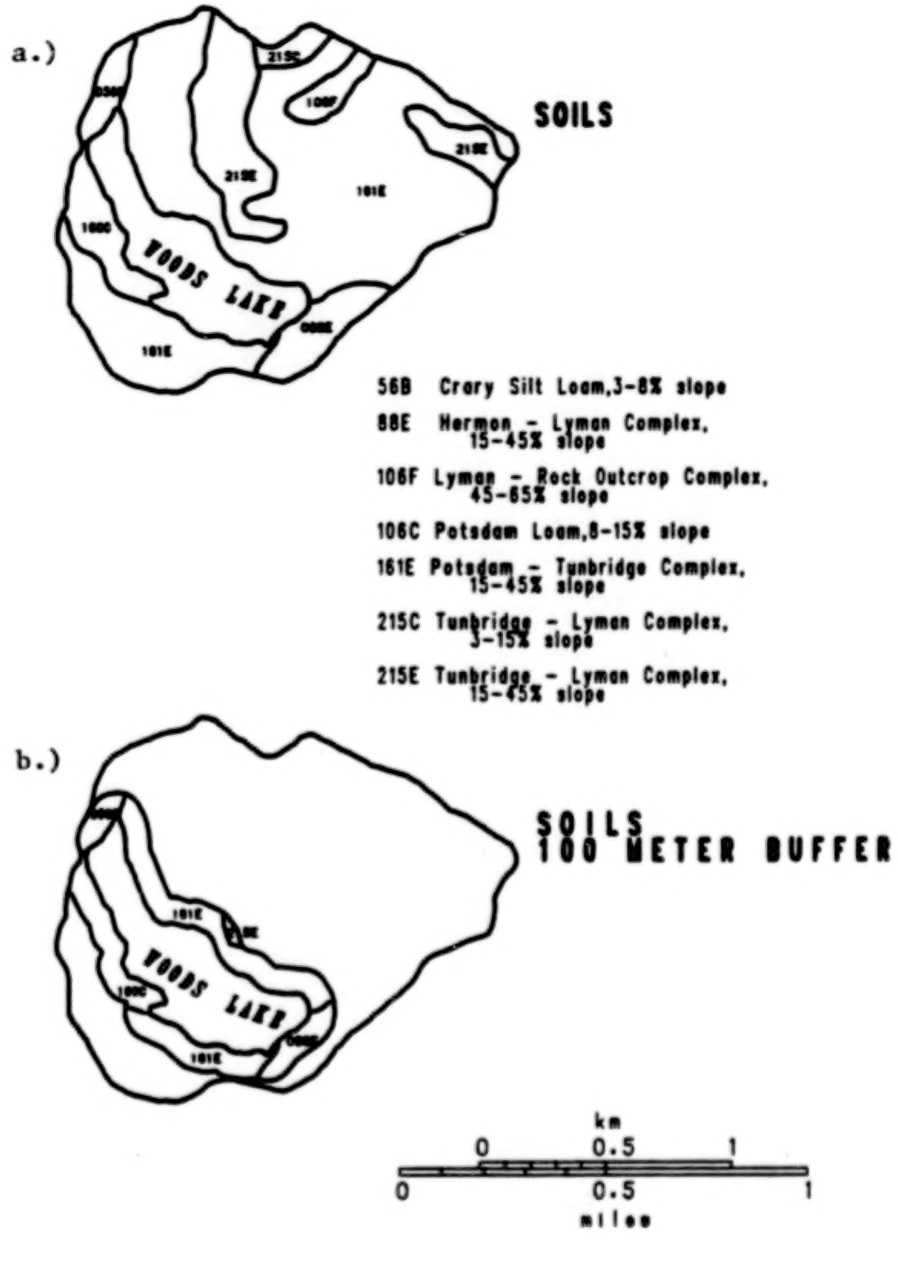

Figure 2. Soils of the Woods Lake, New York watershed including those soils within 100 meters of the outlet lake.

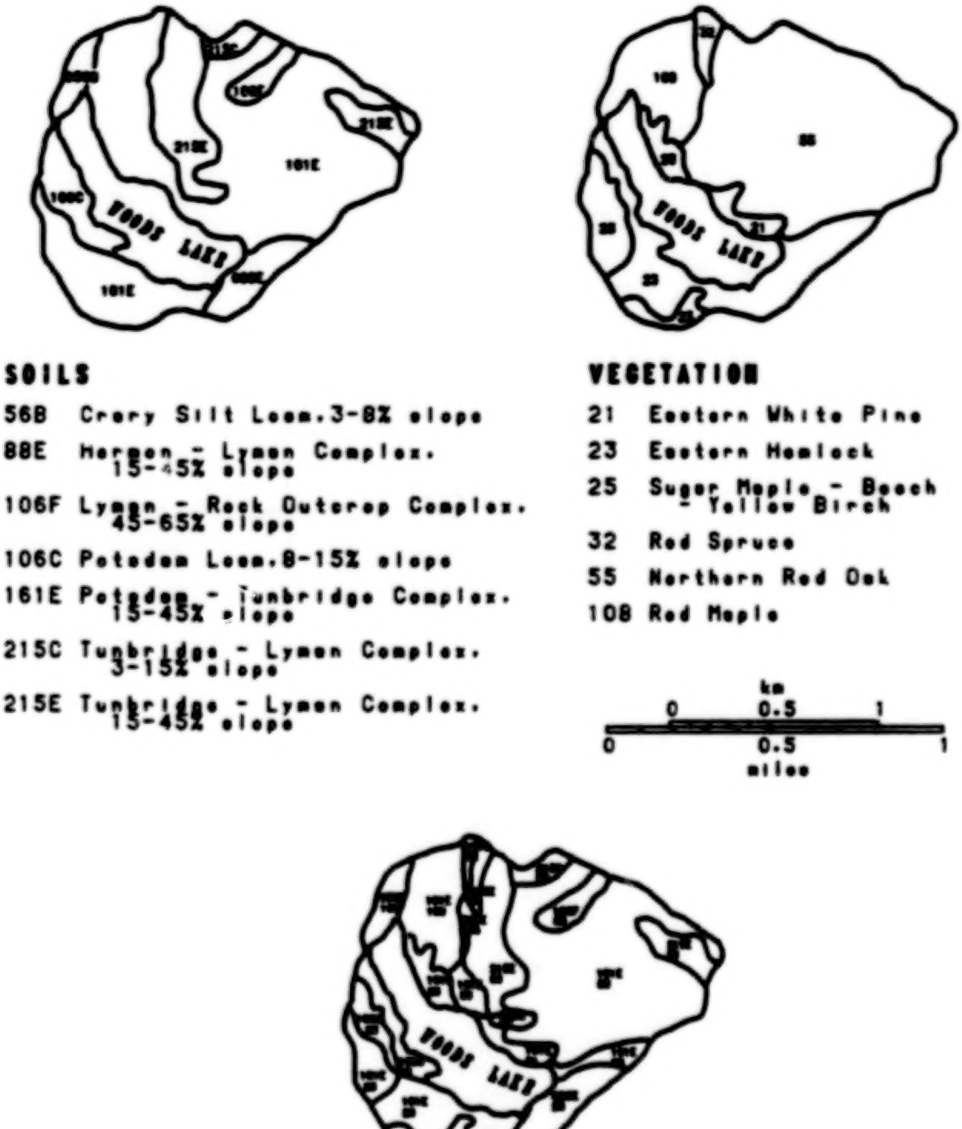

Figure 3. Aggregated map units representing the intersection of the soils and vegetation layers.

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data collection sites (Figure 4)* and, more importantly, the appropriateness of individual sites with respect to regional interpretation and integration.

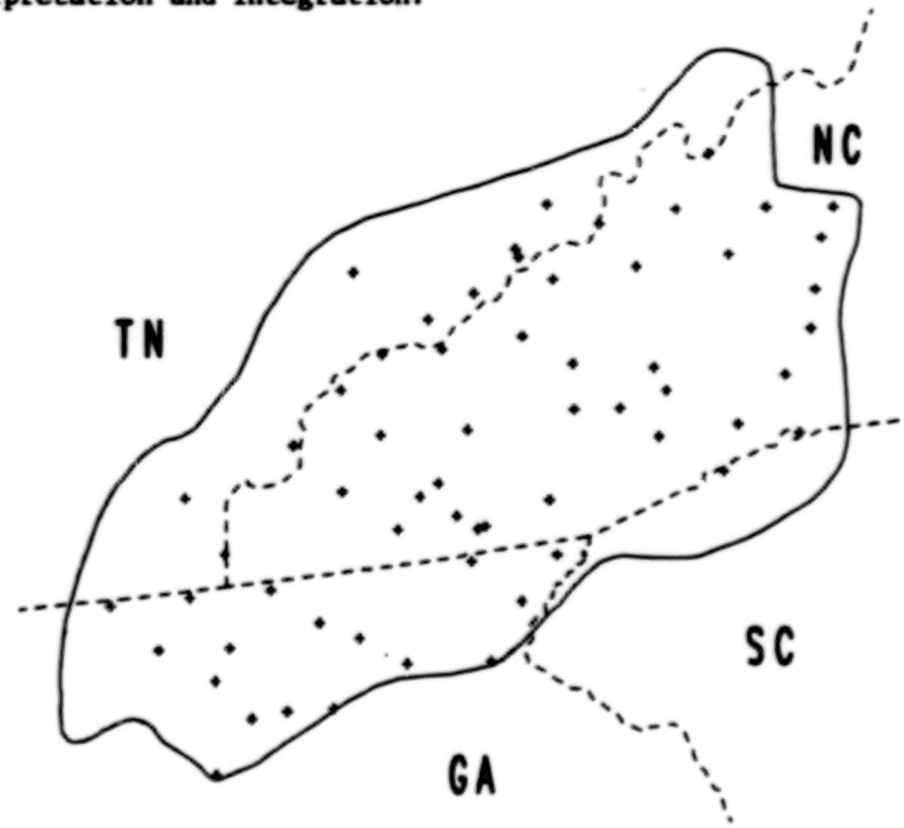

Figure 4. Site map depicting sub-regional distribution of NSWS streams in the SBRP.

Circle maps depict DDRP sites and the associated value for a particular variable, particularly observed or modeled chemical data (Figure 5). In addition to portraying the spatial distribution of single variables, circle maps can be used to display bi-variate distributions by using shade patterns and circle size to indicate the spatial variation of two variables (e.g., alkalinity represented by shade patterns and watershed area by size of the circle).

The spatial patterns of chemical and other characteristics across the regions can also be illustrated by Thiessen polygons. Thiessen polygons represent the 'nearest neighbor' area to a discrete point. These are used as a simple spatial tool to depict broad geographical trends in the data (Figure 6).

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*The present regions of concern for the DDRP include the northeastern U.S. and the Southern Blue Ridge Province. For the purposes of display, a subset of the SBRP is depicted. All depicted techniques, however, can be applied throughout the regions.

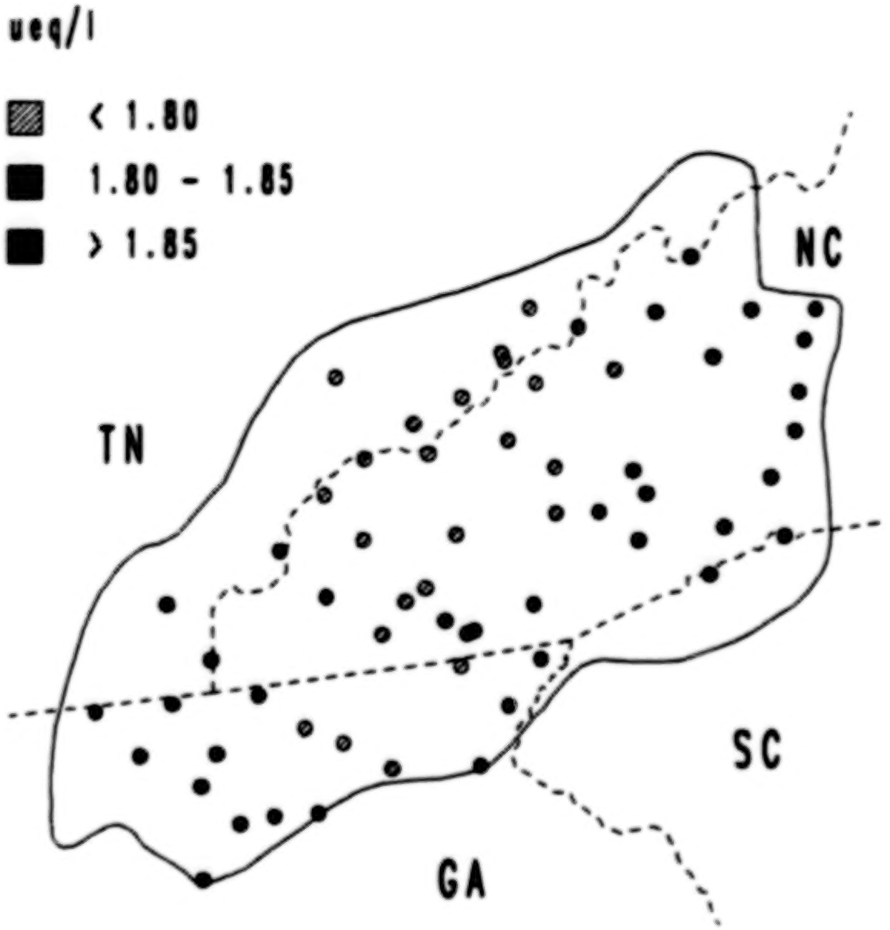

Figure 5. Circle map depicting sulfate concentrations in SBRP streams. Data is from the EPA's NSWS.

GIS-based contouring and interpolation algorithms are used for a variety of analyses, including both descriptive and analytical procedures. As a purely descriptive measure, contour maps (both automated and interpretive)* are used for display and interpretation of the regional variability of selected physical, chemical or biological characteristics (Figure 7). Contour maps are also used in analytical procedures as an interpolation tool. When the GIS is used for automated interpolation, it functions as a non-biased, repeatable procedure for the estimation of point values for specific locations. These interpolated values are subsequently used as input into a variety of analytical procedures and predictive models.

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*Automated contour maps are generated using a computer algorithm, generally linear interpolation. Interpretive contour maps depict contours drawn with 'expert opinion', taking into account spatially distributed variables such as elevation, topography, etc..

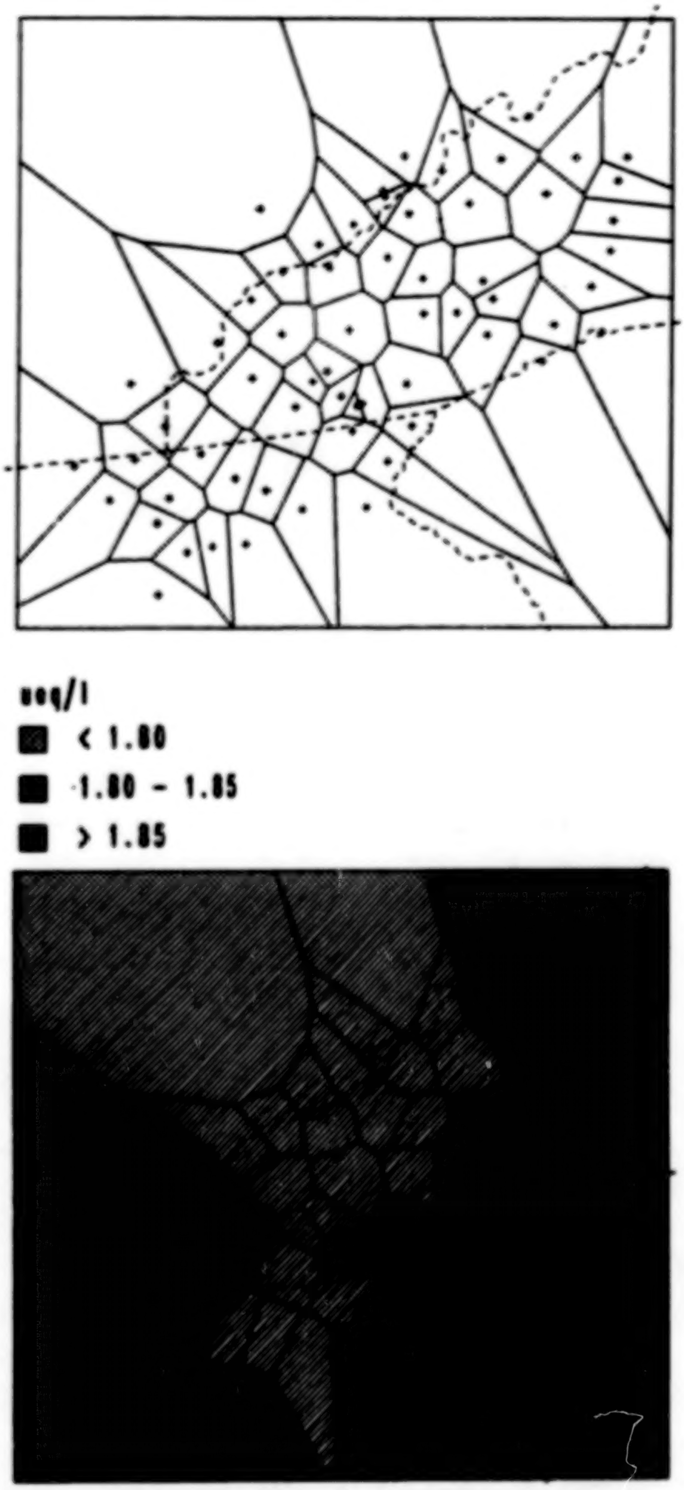

Figure 6. Thiessen polygons for NSWS streams in the SBRP. Shade patterns represent sulfate concentation of SBRP streams. Data are from the EPA's NSWS.

Figure 7. Automated contour map depicting SBRP long term runoff interpolated to selected DDRP stream sites.

Circle, Thiessen, and contour maps are used primarily to display the spatial patterns associated with existing measured chemical or physical data, such as maps depicting sulfate concentrations in NSWS lakes. These maps are also used to display and/or analyze model results, such as computed percent sulfur retention. The ability to efficiently portray various physical variables and/or model results is vital to the DDRP. In particular the GIS allows researchers to interactively examine changes in the spatial patterns or geographical extent of model results given changes in input variables (e.g., what might be the number and distribution of future acidic systems given a decrease in sulfur deposition within the region).

4.REGIONALIZATION AND EXTRAPOLATION OF RESULTS

GIS-based regionalization involves extrapolating data obtained from DDRP analyses to the region as a whole. Inferences concerning the population of lakes or streams can be drawn with regard to the long-term response of surface waters to continued acidic deposition. Apparent associations or relationships among the DDRP dataset and appropriate regional maps can be examined within the GIS environment. In addition, appropriate limits of the extrapolation based on regional boundaries or characteristics can be evaluated.

Thiessen polygon maps are being used to display selected variables within the DDRP. Regional boundaries, such as alkalinity regions, are frequently incorporated as limitations or bounds to the derived Thiessen polygons, inasmuch as the original sampling scheme used these strata to define the DDRP regions (Figure 8).

Although GIS-based regionalization is in its infancy, the DDRP is evaluating the appropriateness of this type of analysis. Regionalization and extrapolation of results based on regional maps (e.g., Major Land and Resource Area maps, regional soils maps) should prove to be useful in the investigation of the applicability and associated uncertainty of various regionalization strategies.

5.SUMMARY

The DDRP uses the GIS for a variety of analyses, including both descriptive and analytical procedures. These types of analyses contribute significantly to all levels of research within the DDRP, from system description to predictive models. Existing data and/or modeled results can be displayed and analyzed with the aid of the GIS. The effect of varying input conditions and/or assumptions can be investigated with regard to the spatial distribution of watersheds exhibiting a range of chemical response times. Other sources of data can be added, modified, or displayed as needed. This ability to incorporate and analyze data (both tabular and mapped) from a variety of sources allows researchers at the EPA's Environmental Research Laboratory in Corvallis the flexibility to interactively examine a variety of combinations of data and to test various hypotheses concerning the long-term response of surface waters to continued acidic deposition.

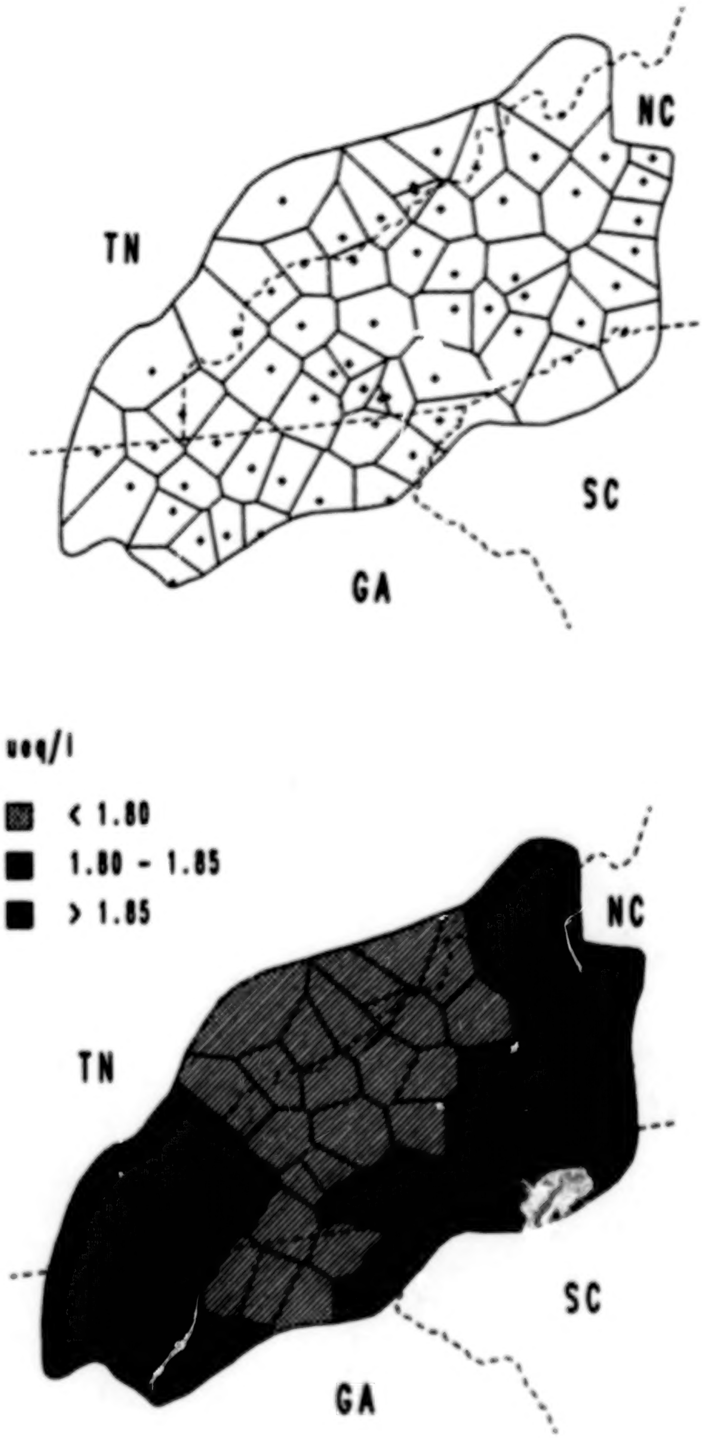

Figure 8. Thiessen polygon for NSWS streams in the SBRP. Polygons have been clipped by sub-region boundaries. Shade patterns represent sulfate concentrations of SBRP streams. Data are from the EPA's NSWS.

TWO-DIMENSIONAL DISPLAY OF GEOGRAPHICALLY-REFERENCED THREE-DIMENSIONAL HYDROLOGIC VECTOR FIELDS

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1. INTRODUCTION

The U.S. Geological Survey uses numerical finite-difference models for the analysis and assessment of regional aquifer systems. The limited graphical output from available flow models generally is cumbersome to use and interpret. In particular, graphics may not be geographically referenced (georeferenced), and may give only limited information regarding the three-dimensional flow characteristics and intertemporal response of the aquifer.

An alternative graphical technique is described in this paper to overcome these difficulties. A means of depicting the three-dimensional flow patterns of an aquifer by use of sequential, two-dimensional color graphics is described. Then, a monochrome graphic, modified to meet publication requirements, is used to illustrate a simulation of ground-water flow in the Monmouth County region of east-central New Jersey. The flux field of an aquifer underlying the region is overlayed on cultural and physiographic features.

2. THE NEW JERSEY REGIONAL AQUIFER SYSTEM ANALYSIS MODEL

The U.S. Geological Survey's New Jersey Regional Aquifer Systems Analysis (RASA) Program was initiated in 1978 to develop a quantitative assessment of the ground-water system in New Jersey. A major part of the assessment was the construction of a three-dimensional computer-simulation model (Martin, 1987; Leahy, 1982) of the state's Coastal Plain aquifer system. The model uses finite-difference methods to simulate ground-water flow in a system of 10 regional aquifers that form a layered, water-bearing sequence of unconsolidated sediments beneath the State's Coastal Plain.

Nine simulations of ground-water flux have been done for the period 1896 to 1981. The number of years covered by each simulation appears in table 1.

Table 1 -- Elapsed time between model simulations.

Simulation Number	1	2	3	4	5	6	7	8	9
Number of Years in Simulation	25	25	7	5	7	3	5	5	3

Each simulation provides estimates of hydraulic head, flux, and flow velocity at each of 1,323 nodes in the finite-difference grid. Flux and velocity form vector fields that describe regional patterns of water movement in New Jersey.

3. GRAPHIC DISPLAY OF MODEL OUTPUT

3.1 Conventional Methods of Display

Conventionally, flux and velocity estimates of the model have been displayed either as static video images or as hard-copy plots. Usually, these are in the form of a hydraulic-head map. This map is a potentiometric surface in which undisplayed velocity vectors must be visualized as being normal to the potential contours. Less frequently, plots of the two-dimensional components of three-dimensional velocity fields or contour maps of flow speed are used to analyze the regional hydrologic dynamics of an aquifer. Therefore, to visualize a three-dimensional field using these planar diagrams will take at least two sets of diagrams--one set normal to either the x or y (horizontal) axis, and one normal to the z (vertical) axis. Thus, the intertemporal velocity dynamics of the system might typically be visualized by viewing, in sequence, a series of monochrome contour maps of head potential or the horizontal components of a three-dimensional field.

Likewise, to review the spatial dynamics of a regional aquifer system, a series of maps representing hydraulic head in increasingly deeper layers of the system, or through a series of vertical slices, would be examined sequentially. Displays commonly are not georeferenced, so that analysis of the relation of hydrological and spatial features may be difficult.

The information conveyed in these graphics is limited by the use of monochrome rather than colored displays, by the abstraction of an

actual vector field into its corresponding potential map, and by the static nature. It is not difficult to remove these shortcomings. In the following section, an improved method of display is described.

3.2 Dynamic Georeferenced Displays

One way of improving visual representation of a hydrological vector field is to display the vectors themselves rather than their corresponding potential field. This may be done by computing the resultant vector for each node of the model grid, normalizing and scaling the resultant so that projections do not overlap, and then assigning colors to indicate whether the resultant is rising out of the layer, descending below the layer, or remaining inside it. In order to improve readibility, width rather than length of the displayed vector is associated with magnitude. The resulting field can then be converted into a georeferenced coverage--that is, geographically-structured data set--using a geographical information system (GIS). Finally, the images can be viewed to provide a computer-animated simulation of the field's dynamics.

This method allows the analyst to examine aquifer response in a more intuitive and synoptic fashion than do the traditional techniques described in the preceding section. Because this graphical method incorporates more information in each image, it economizes on hardware resources.

The process for producing figure 1 is described below. First, a series of nine ground-water simulations were conducted using the New Jersey RASA model. In general, these may be either a time series for some given set of locations or a spatial series for a specified time. Each simulation results in a flux, velocity, or head field. Next, for each simulation, a postprocessor is used to determine resultants in three dimensions and project them onto the x-y plane. The projected field is then standardized and scaled to dimensions appropriate for use by an ARC/INFO[1] GIS. Colors distinguishing upward and downward flow components; vector widths corresponding to vector magnitudes are assigned during this phase.

The GIS registers the processed field to a U.S. Geological Survey digital base map, and then generates a coverage. Output from ARC/INFO is converted to an Internation Business Machines Enhanced Graphics format and stored as a disk file. Further processing of the

disk file produces the image sequence. An alternative, unanimated, hard-copy output format is discussed in the following section.

4. PRINTED DISPLAY OUTPUT FOR MONMOUTH COUNTY, NEW JERSEY

Monmouth County is located in east-central New Jersey and borders the south side of Raritan Bay. For several decades, the county has undergone increasingly intense industrial and residential development. This development has increased demands on the region's aquifer system, which in turn has led to increased ground-water withdrawls and the formation of a substantial cone of depression in certain stressed layers of the system.

Although it is not possible to present the animation and color features of the methods described here because of publication limitations, typical output, modified to suit single-color reproduction is shown in Figure 1, below. In this diagram, a flux field is shown registered to the map component of the digital database for Monmouth County, New Jersey. The database also includes coverages for drainage basin boundaries, land use, locations of wells, geology, soils, and other types of spatial data useful for planning and analyzing the region's water resources.

Several differences exist between the flux representation shown in figure 1 and the animated, color-coded version. Flux resultants rising from this layer of the aquifer into the layer above or descending into the layer below are shown by map symbols attached to the tails of the flux vectors instead of being shown by vector color. An alternative form of magnitude representation also is used. Here, flux magnitude is discretized into four classes rather than being shown as a continuous quantity. This is useful for emphasizing regions associated with large magnitudes of flux. Like their color-coded counterparts, monochrome images such as those of Figure 1 are easily animated, though not as easily read in animation.

In the example figure, a specified head boundary forms the northwestern boundary and the northeastern edge of the region is modeled as a no-flow boundary. Flux vectors near the northeastern boundary show an increase in magnitude and an upward flow. This corresponds to predevelopment conditions under which water discharged into Raritan Bay. Thinning of the aquifer toward the northwest accounts for the increase in flux magnitudes. The northwestern boundary also is the outcrop of the aquifer. Because this region

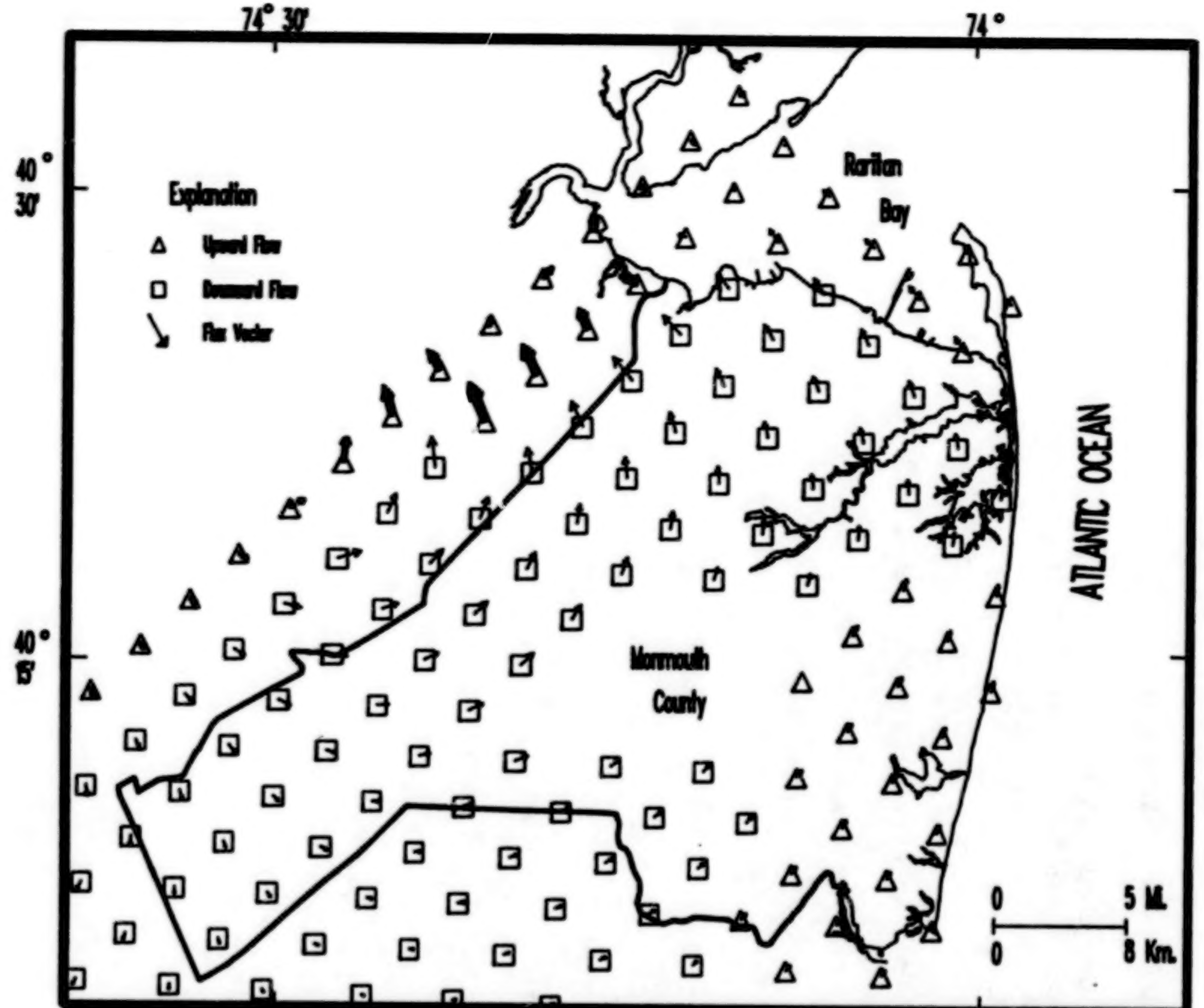

Figure 1. — Hypothetical flux vectors, Monmouth County and vicinity, New Jersey.

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offers the least resistance to flow, velocity is further increased. Moving downdip (southeast) in the aquifer, the vector field indicates a relatively uniform flux downward, except near the southeastern boundary. This is because the overlying confining unit is thick and has little leakage.

5. SUMMARY AND CONCLUSIONS

Graphic presentation formats currently in use by the U.S. Geological Survey and elsewhere for displaying results of numerical models are sometimes difficult to read and inefficient in the way they display data. An improved method of depicting model output graphically through the use of color and animation has been described. In addition, georeferencing of this enhanced display improves geographical interpretibility. The display format may easily be modified to produce monochrome printed copy if that is desired. Results are illustrated in an example using RASA model output for the Monmouth County region of New Jersey.

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GIS FILE REQUIREMENTS FOR REGIONAL SCALE WATER RESOURCES ANALYSIS

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ABSTRACT

Designers of a geographic information system for a particular application must begin by recognizing the need to make three difficult choices. The first is between two mutually incompatible approaches to data -- regional inventory (counting) and parcel classification (tagging). The former uses point sampling to provide a statistically valid estimate of the total quantity of a resource within general areas. The latter tries to characterize resources at specific sites. The choice of perspectives, unfortunately, must be made prior to data collection, and it has a pervasive effect on the structure of files and the treatment of original data. Moreover, merging a tag file with a count file can introduce very large errors in regional inventory or parcel classification.

The second fundamental decision deals with the spatial resolution of data collection and storage. A regional analysis of a resource usually uses fairly large areal units in order to minimize computation time. Most water resource simulations will provide satisfactory results with count data from between one hundred and one thousand sample points. The individual analysis units in a typical regional study will therefore be on the order of one to ten square kilometers in size. A much smaller spatial unit is technologically feasible but legally indefensible, because it may tempt people to view the results as more precise, mathematically and geographically, than they really are. For most hydrologic analyses, the output precision will almost certainly be limited by the precision of the input variables, some of which typically have a measurement error of ten or twenty percent. The data files in a GIS should include a clear record of the spatial resolution and measurement precision of the original data, along with a description of any transformations that have taken place.

The third basic consideration involves the need for strict punctual relationality in the data files. A typical water resource simulation works by merging a number of data files (rainfall, land cover, soil, terrain, etc.) in order to calculate runoff, erosion, transpiration, or groundwater recharge. This kind of model assumes that each input variable was measured at exactly the same location. That attribute, referred to as *punctual relationality*, is at best difficult to achieve; the structure of the GIS should have safeguards against presuming punctual relationality where it does not exist.

1. INTRODUCTION

This is a partial summary of research on design considerations for a water resources GIS that is intended for use at a regional scale of analysis (100 to 10,000 square kilometers). Water resources planning and management involve many different kinds of geographical analysis that can be performed with GIS. These in turn require some familiarity with a number of different GIS "languages" that have evolved, more or less independently, within disciplines such as applied climatology (interpolation between point observations), forestry (sampling within delimited areas), hydraulics (studying linear connections in stream systems), and military engineering (modeling terrain surfaces). These different methods of spatial analysis also need to be coupled with the time dimension in order to evaluate a hydrologic system in its entirety.

The historic record of hydrologic events, even if it did exist for a given area of interest, is not an adequate guide for decision-making in times of environmental change. Hydrologic simulation can offer a better perspective, especially if used with a GIS that can document spatial differences and temporal trends in environmental conditions. A careful look at existing hydrologic simulation models reveals a not unexpected dichotomy. Most existing models have been formulated at either a very broad scale (the entire Missouri Basin) or a minute one (a single slope or small catchment). Continental studies often ignore local variations in land slope, soil traits, and vegetation cover, because the effects of different micro-environments are frequently perceived as canceling each other out. At the other extreme, a site-scale engineering procedure can afford, because of its small study area, to pay careful attention to the myriad of local details. Between the continental and local is the regional scale -- study areas that are large enough to have significant amounts of internal variation, yet too small to benefit from canceling effects.

The application of GIS to the analysis of water resources at the regional scale forces us first to choose between two mutually incompatible approaches to data -- regional inventory (the count method) and parcel classification (the tag method), which we describe in detail below. Our answer to that fundamental question should guide the design of files and the treatment of original data. In this paper, we will summarize six interrelated issues that involve structural logic, cell size, the treatment of surface water, and the relational data requirements of the analysis.

2. THE QUESTION OF TAGGING VERSUS COUNTING

The data in a resource GIS often begin as simple site descriptions, made by an observer who categorizes or measures some aspect of the landscape at specific places. In the process of trying to display a larger area, a map-maker must generalize in order to make sense out of the mass of individual sample points.

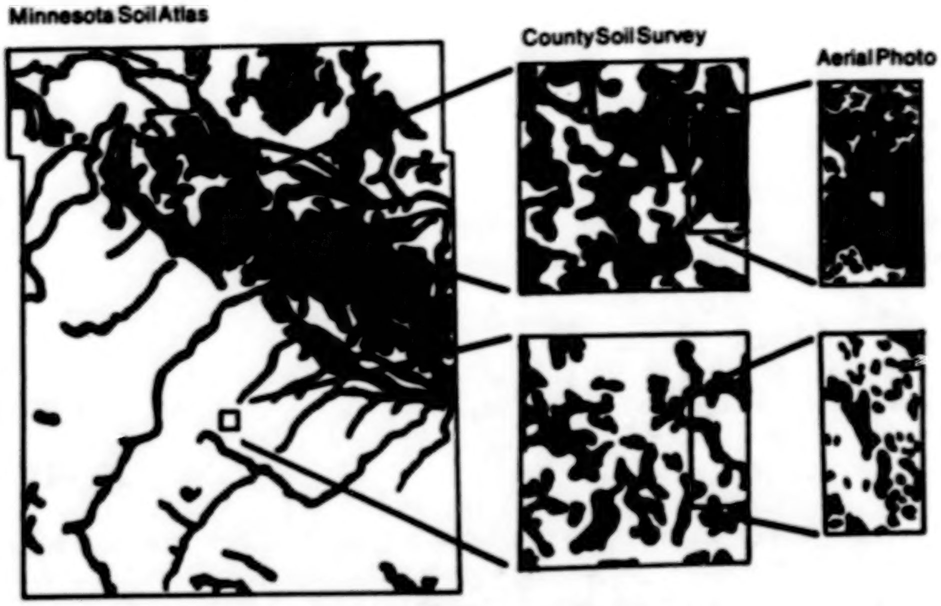
This generalization is usually done by following one of two procedures, which we will refer to as tagging and counting. A clear distinction between these approaches is essential for water resources applications, because a count system cannot provide valid answers for tag questions, and vice versa (Gersmehl, Brown & Anderson, 1987). The choice between the two approaches, unfortunately, must be made at the beginning of data collection. For that reason, the strengths and weaknesses of the two approaches must be understood before we can make an informed choice of the one to use in a water resources GIS.

The tag approach to the process of generalization begins by delimiting a mapped area and then categorizing (tagging) it on the basis of the dominant (most extensive or most numerous) trait within it. If boundaries are drawn with some care, this method can provide a reasonably accurate description of the mapped area (for a review of these principles, see Hole and Campbell, 1985). A good tag map is essential for the implementation of most land-use policy. However, a tag GIS has the disadvantage of excluding from further consideration any phenomenon that occurs in a scattered pattern and therefore never dominates an area as large as the minimum size of delineation on the map. This omission is of little concern in a descriptive study, but it can have profound implications for simulation analysis, because some phenomena have a hydrologic importance that is much greater than the space they occupy (Anderson et al., 1986). Figure 1 summarizes a study that shows how tag maps systematically omit an extensive but areally subordinate category of soils (Gersmehl, Corbett and Greene, 1987). These soils may account for more than half of the storm runoff, even though they occupy less than one-quarter of the area.

An alternative way to generalize is to make an inventory of a mapped area by counting the frequency of occurrence of particular phenomena within the area. The count approach has great flexibility in changing scale; as mapping units increase in size, hydrologically important but areally minor phenomena can continue to be part of the analysis, because the count method preserves the statistics of the original data sample (Figure 2).

On the minus side, the count method can cause sample data to lose their locational specificity within the count area. Moreover, a count can consume much more computer memory and processing time than a simple tag map. For example, a tag file of land use requires only a single letter to indicate whether a data cell area is predominantly forest (F), rowcrops (R), pasture (P), industrial (I), and so forth. A complete inventory, by contrast, requires as many files as there are classes for the data. In the real world, however, the storage costs are roughly comparable, because a count file can use larger data cells. In a recent study of soil mapping in four different geomorphic regions, tag maps with a four-hectare resolution had errors that ranged from 21 to 49 percent, whereas the error for a count system with 64-hectare cells (16 times as large) was between 2 and 24 percent (Figure 3).

Figure 1. Tag maps of soils in Lyon County
(Dark areas are poorly drained soils.)



Each map accurately depicts the *dominant* soil in various areas, but all delimited areas contain significant amounts of dissimilar soil.

Figure 2. Effect of scale change on forest area shown in tag and count data files.

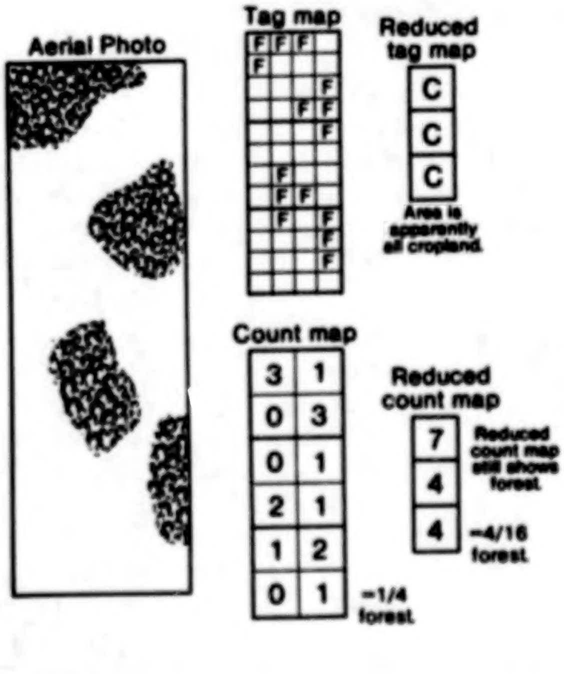
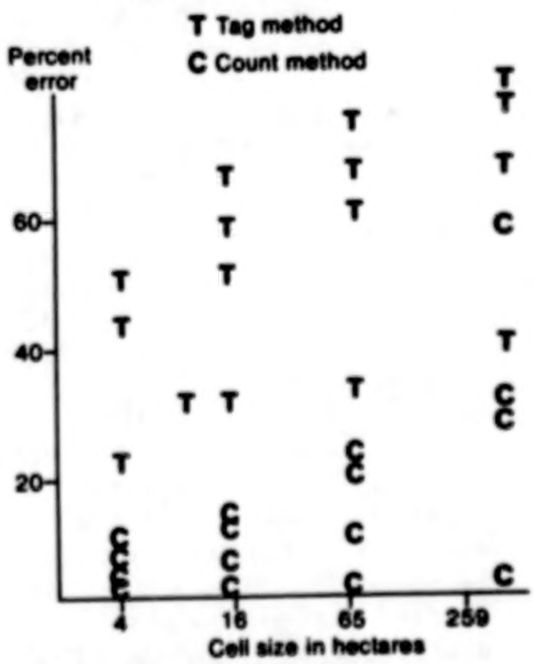


Figure 3. Percent error in tag and count data files of soils in four geomorphic regions.



Adapted from Gersmehl & Gersmehl, 1982.

For the purposes of a water resource simulation, a GIS with a count approach appears to have two significant advantages: smaller errors and better relational matching between data files. A tag approach, by contrast, is more desirable from an administrative point of view, because it can label areas for zoning or similar purposes. Inadvertent merging of count and tag files (or using count files to answer tag questions and vice versa) can introduce order-of-magnitude errors. For that reason, *the file header should clearly identify the perspective used in aggregating the data, and the software should not permit the blind merging of tag and count files. Research to assess the error associated with such mergers should have a high priority.*

3. IS TAG-VERSUS-COUNT A TEMPORARY QUESTION?

Before we look more closely at the topic of data relationality, we should briefly consider the possibility that the question of tag versus count is an artificial one, caused by temporary limitations in technology. As costs of data storage decrease and processing speeds increase, computers can work at ever finer resolution. Smaller data cells are more likely to be homogeneous, which will reduce errors of tagging and maintain count accuracy. Those who look to tomorrow's computers to solve this data problem, however, should realize that the capabilities of today's computers are already more than adequate for much of the data we have or are likely to get in the near future.

It is true that if we could accurately describe a landscape at one-meter intervals, those descriptions would probably serve for either counting or tagging purposes. It is also true that remote-sensing techniques can provide some kinds of data at that fine a resolution (e.g. extremely detailed contour maps made by automated photogrammetry of low-altitude aerial photographs). But we must be willing to admit that many other kinds of data, such as aquifer thickness, soil erodibility, rainfall intensity, or channel geometry, are not likely to be measured at anywhere near that fine resolution. When we concede that, we must confront the blunt fact that merging several data files of unequal resolution cannot produce an output file of any greater attribute and locational reliability than the least precisely measured input file. For example, we cannot measure slope at ten-meter intervals and soil traits at hundred-meter intervals and expect to produce a valid map of soil erosion potential at a ten-meter resolution. In fact (and this is a key point), a well designed count system with sample points at 500-meter spacing will probably produce a more accurate estimate of erosion potential than a blind merging of a ten-meter terrain file with the hundred-meter polygons in a detailed soil survey (Gersmehl, 1987). Thus, *the data file header should also indicate the original spatial resolution of the data, and the software should not allow display of merged files at an inappropriate resolution. Research to assess the error caused by resolution changes and file mergers should have high priority.*

4. ONE UNIQUE PROBLEM WITH HYDROGRAPHIC DATA

A geographic information system for lake data presents some unique problems, because lakes can serve as both dependent and independent variables. At the scale of the state as a whole, most lakes appear as point data; at a local scale, lakes can be viewed as area units, much like forests and crop fields. At regional scales, some appear as areas while others remain too small to be captured by a tag map. The designer of a water-resources GIS must decide if its purpose is to display internal variations within big lakes or to describe how lakes respond, as units, to watershed changes. If the focus is on the former, a high-resolution tag file is preferable. That option is not necessarily limited by the use of a count approach for the watershed data, but the GIS will need to include a separate geocoded file of water bodies that did not happen to be sampled in the count file. Redundancy between the lake and surface cover files can be eliminated by noting only the *presence* of water bodies in the regional count and storing all descriptive data about them in the separate lake file. *Because of the ambiguous role of surface water bodies, a water-resources GIS may work better if it includes files that are known, a priori, to be functionally incompatible. Research on algorithms for combining such files should have high priority.*

5. THE NEED FOR PUNCTUALLY RELATIONAL DATA

A typical water simulation model uses a number of data files (rainfall, land cover, soil, terrain, etc.) in order to calculate runoff, infiltration, soil erosion, transpiration, or groundwater recharge. The simulation takes various kinds of input data and combines them according to a set of equations that have been derived theoretically or empirically. For that reason, the models all rest on the presumption that each variable was measured at exactly the same location (Gersmehl, Brown & Anderson, 1987). This attribute, referred to as the *punctually relational* character of GIS data files, is at best difficult to achieve (Brown et. al., 1987).

Some hydrologic simulations deal with the lack of punctual relationality by averaging data over an entire watershed. Others use regional surrogates for some difficult-to-measure kinds of data (e.g. the slope-length variable in AGNPS (Onstad et. al., 1985)). In both cases, the averaging assumptions can widen the error band of a calculation considerably. Consider a simple area, half sandy flats and half clayey hills, with a land cover that is half straight-row corn and half pasture. A model that assumes equal distribution of cover types on the soil types will greatly over-estimate runoff and sediment production, if in the real world the corn is only on the flat, coarse soils. A good record of the *combination* of traits at a number of sample points is more important for a hydrologic simulation than the exact *position* of the sites in the geodetic survey system.

Maintaining relationality between point-sample files, however, is difficult when different kinds of data are gathered at different times by different people. A water-resources GIS should have a sampling design that is punctually relational, has great flexibility in sample size, and still is easy to administer. We believe that this combination of attributes is easiest to maintain if the sampling design uses a simple formula based on the UTM coordinate system (an example is shown in Figure 4, from Gersmehl, Brown & Anderson, 1987). Details of sample density and placement must be worked out for each study area. *A description of the sampling design should be in the file header, and research to determine the effectiveness of different coordinate-based sampling designs should have high priority.*

6. ANOTHER LOOK AT THE QUESTION OF SAMPLE DENSITY AND CELL SIZE

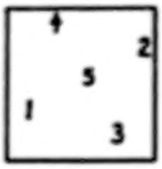
As we shift from field-size to regional studies, the scale of analysis (and the resulting level of data abstraction) often requires that we limit the number of sample points in order to minimize data collection and computation time. As part of our study, we examined the data requirements and processing algorithms for twelve of the most widely used hydrologic simulations (summarized in Table 2-1 of Brown and Gersmehl, 1987). Most of these models provide satisfactory results when the number of discrete sub-areas is in the range of one hundred to one thousand. A regional study area will therefore have data cells that are on the order of one to ten square kilometers in size. A smaller spatial resolution is well within our technical capability, but it may tempt people to view the results as more precise, mathematically and geographically, than they really are. For most hydrologic analyses, the results will almost certainly be limited by the measurement precision of the variables, which often is in the tens of percents for the least precise variables used.

The ideal scale (and therefore the optimal cell size), for regional water resources analysis is one that reduces the counting error to an acceptable level and minimizes the locational error of the data. The number of samples should be sufficiently large to reflect all hydrologically important components of the map. For example, a feature may occupy only one percent of the area of one region but account for five percent of the variability of runoff or evaporation there. In another place, all important features may cover at least one-fifth of the area. In both cases, an effective GIS design requires a sample large enough to capture the spatial extent of the hydrologically important features, but in the second case a total sample of about forty will provide as much statistical accuracy as a sample of several hundred in the first case.

Clearly, it is not possible to recommend a single sample size as a universal basis for regional inventory, nor is the ideal scale the same for all questions. One must design a GIS in the same way as a statistical study, namely by conducting a valid pretest in order to determine the relevant characteristics of the data in a given study

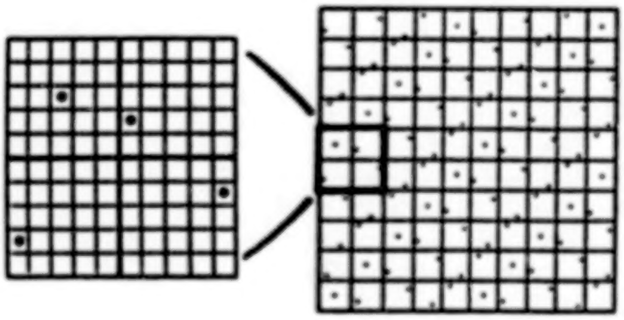
A (COMPROMISE) STRATIFIED UNALIGNED SAMPLING DESIGN FOR A WATER RESOURCES INFORMATION SYSTEM

For maximum utility in hydrologic simulation, a water-resources GIS should use some form of ***unaligned point sampling*** to gather and store data. Selecting unbiased sample points can be a difficult task, even for someone working alone. It is even harder to choose a sampling procedure that will be be used independently by workers from different agencies to gather data that are supposed to be spatially relational.

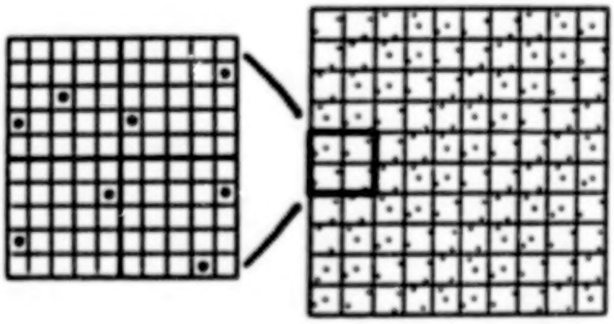


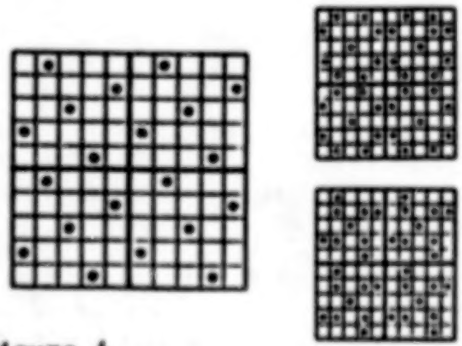
The situation demands a compromise between a need for *randomness*, to maximize statistical validity, and the desirability of *order*, to avoid confusion in doing the sampling. Order is easy to communicate if it is tied to the underlying coordinate system. In the example illustrated here, the sample point within a given square-kilometer cell depends on the UTM coordinates of the cell. To find the sample point, subtract the northing from the easting, and if the kilometer digit of the result is 1 or 6, use sample point 1; if 2 or 7, use point 2, and so on.

With this procedure, a single data point per square kilometer would yield a diagonal pattern that is not perfectly aligned. Adjacent cells are sampled in different places, an essential trait if the sampling is to be statistically valid.



Taking two samples, one at the designated point and one at the point that is numbered one less, would give a reasonable pattern with two data points per square kilometer. Half of these points would still be strictly relational with a file of data gathered at one point per square kilometer.





Five points per square kilometer would involve sampling at all of the designated points, some of which would be relational with less intensively sampled data. The small diagrams show alternative ways to gather nine samples per data cell. Taking one sample in each 200-meter area would give 25 data points per square-kilometer data cell; the next logical increment is one sample every 100 meters. We do not necessarily recommend this particular sampling sequence, but it would be very desirable to have one strategy for all agencies to follow in gathering data.

Figure 4.

area (Brann, House, and Lund, 1981). This problem is complicated by the requirement that data be punctually relational for a hydrologic simulation. *The ideal cell size is thus a variable that depends on the interaction between analytical methods, study area traits, and the need for punctual relationality with other data files. Research on efficient pretesting methods for a GIS should have high priority.*

7. ANOTHER UNIQUE PROBLEM WITH HYDROGRAPHIC DATA

Each reach of a stream is part of a directed linear system -- it can be affected by all terrain and tributaries that lie upstream and, in turn, can affect all downstream parts of the drainage system. The *vertical* relationality described above is thus necessary but not sufficient to support simulations of hydrologic processes. The structure of typical cell-based GIS must be modified to accommodate the *horizontal* relationality of stream systems (Brown et. al. 1987).

These modifications introduce another dimension that can cause problems if data files are merged indiscriminately. *The nature and degree of implied relationality of each data file should therefore also be recorded in the file header. Research on efficient ways of indicating horizontal relationality should have high priority.*

8. SUMMARY

In this report on considerations that affect the design of a GIS for water-resources analysis, we have shown how a data file with a tag perspective can systematically under-represent key variables. This problem is not confined to water resources. Important forage resources and habitats for livestock and wildlife may be missed by a tag analysis. A count approach is usually superior for resource assessments, but only if the sample is sufficient to describe the coverage of important species or resources. This is nothing more (or less) than another way of saying that the sampling strategy needed to create accurate data files may vary from place to place and from application to application.

The problem of ensuring punctual relationality among sample points must be addressed in any count-based GIS. The sample design must be easy to follow, especially when information is volatile and needs frequent updating. Details of tag or count perspective, sample placement, and implied relationality should be recorded in the file header (an extension of the list proposed by Chrisman, 1985). The analysis software must then read the header record and incorporate the data limitations of the file structure into the procedures that select techniques for data manipulation and display. The result of these precautions, however, will be a GIS that can make a hydrologic simulation an order of magnitude more accurate than what can be accomplished by current methods of overlaying tag data files and producing composite maps of resources.

ACKNOWLEDGEMENTS

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MAP DATA DIGITIZING, EDITING AND AUTOMATIC HYDROLOGICAL NETWORK RECONSTRUCTION

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ABSTRACT

Geographic information systems (GISs) have been recognized by both the public and private sectors as invaluable tools in planning and decision making for resource management in world economies. Data acquisition is an essential part of such systems because without appropriate data there is no useful system. Because land related data are mostly available in analogue map form, the data acquisition stage usually involves a digitizing and editing phase, so that the data may be structured and encoded into the GIS database. This research has investigated and catalogued many of the current issues in digital acquisition of map data, has applied some of these to map data for a test area in the Kananaskis Valley of southwestern Alberta, and has investigated methods for the automatic generation of nodes and flow directions necessary for the geometric and topological reconstruction of a digitized hydrological network. The results show that an approach which is quite simple conceptually enables the fast generation of positionally accurate nodes and, with minimal elevation data, enables the automatic determination of stream flow directions. The final output is most suitable for the generation of an arc/node (semi or fully topological) data structure which, experience has shown, offers the most versatile data manipulation and fastest response times for many GIS tasks.

1. INTRODUCTION

The official definition for a land related information system (LRIS) as adopted by the International Federation of Surveyors (FIG) in 1981 is that it is:

"...a tool for legal, administrative and economic decision making which consists on the one hand of a database containing spatially referenced land related data for a defined area, and on the other hand of procedures and techniques for the systematic collection, updating, processing and distribution of the data. The base for a land related information system is a uniform spatial referencing system for the data in the system, which also facilitates the linking of data within the system with other land related data."

As this definition suggests, the advantages of using an LRIS (or GIS) are in its ability to store large quantities of information of varying themes in a single database and the subsequent ability to quickly integrate, manipulate, overlay and update such information in order to arrive at timely planning decisions. However, a geographic information system only comes into being when there are the necessary computer hardware, software, manpower and appropriate digital data, geometrically and topologically consistent. The importance of the data capture stage cannot therefore be overemphasized. This stage involves the digitization of input data (which are often in analogue form) and their resultant editing, to correct for inconsistencies and attach descriptive attribute codes and spatial relations to the data.

Experience has shown that how data are structured in a GIS database has a great bearing on the kinds of data manipulations possible, and on the processing times also. Various data structures are available for use but the semi and fully topological data structures have been found to be the most versatile, and are favoured for most recently developed systems. The generation of junction nodes is essential to the realization of these structures, since they require the break up of lines and polygons into arcs, running from node to node. The traditional method of data capture is for the operator to physically mark out the arcs and nodes on the map and digitize them as such. This approach, while increasing the time needed for map preparation and digitizing, still requires that the nodes at the various junctions be matched later by software. In addition, the operator traditionally obtains stream flow directions by "always digitizing upstream", thus introducing another element of constraint into the process.

There has therefore been interest of late in the automated generation of nodes from features digitized as they are. De Simone (1985) describes an illfated large-scale British project to restructure digital data in this manner in the usual vector format, and then suggests that a raster approach may be preferable. However, working systems, such as ARC/INFO (Dangermond, 1983) and those under development, such as TIGRIS (Intergraph Corporation, 1986), are sufficient evidence that automated node generation in vector format works. This is preferable to De Simone's approach, which assumes the availability of scanning hardware and raster processing software and, in addition, involves the possible loss of information.

This research thus sought to investigate the automatic generation of junction nodes and flow directions for a digitized hydrological network. This work is related to the Departmental effort to develop a prototype GIS for the Kananaskis Valley of southwestern Alberta (Lodwick et al, 1986). It aimed to contribute to this effort by identifying the problems that can be expected in digitizing and editing data of various themes for the proposed GIS and by developing software for the automated generation of junction nodes and flow

directions that can be used to generate an arc/node data structure. The results of this research are more fully described in Mulaku (1987).

2. DIGITAL MAP DATA AND DATA STRUCTURES

In order to develop and use a GIS, spatial data in analogue form must be converted to digital form. This involves the following stages:

(a) Digitizing, in which the data are converted to digital form by a variety of manual, automatic and semi-automatic methods, and

(b) Editing, whereby the data are checked for errors and geometrical and topological consistency, and any corrections performed.

This cyclical digitizing/editing is the most expensive and time consuming phase in the use and development of a GIS.

2.1 Digital Data

Data may be defined as known facts that are used as a basis for inference or reckoning. For example, the measured lengths and directions of a cadastral lot are data that can be used to infer its area. Digital data are data then that are in such a form that they can be input to, and manipulated by, a digital computer. With land information, data consist of features. A feature is defined as any item on the earth's surface that is significant to the user, e.g. a road or lake. Features may further be grouped into classes. For example, lakes, rivers and glaciers all belong to the hydrological feature class. In digital data, any feature is defined by three properties: its position, its attributes and its relationships to other features.

Feature position consists of locational data that define its spatial extent. Such data may be either in vector or raster form, i.e. represented by points, lines and polygons, or pixels and cells arranged in matrix form. The relative merits of defining feature position in vector or raster form have been much debated (Leberl, 1982; Peuquet, 1978; Theis, 1982; Burrough, 1986; Monmonier, 1982). Attributes are those data that specify the characteristics of a feature. They may be numeric, e.g. area, size, slope, elevation, or they may be semantic, e.g. name, type. Thus a road may be described in terms of its name, road type, construction materials used, width, etc. In order to minimize attribute storage, all positional data with the same attributes may be grouped together (Stevanovic, 1982). Spatial relationships between features, while quite obvious in the graphic form, are not apparent in digital data. These relationships may be proximal (describing the closeness of non-contiguous features), hierarchical (describing the relationship between a feature and its feature class) or topological (describing neighbourhood information) (Lodwick and Feuchtwanger, 1987). Topological relations are very important as digital data are fairly meaningless without them.

2.2 Vector Data Structures for Digitization

As data are collected at the least aggregated level, i.e. as points, data structuring may be defined as the way in which these point data are built up, in order to represent the higher level entities of lines, polygons and any defined intermediates, plus their relationships in digital storage. A good data structure should enable easy data capture, efficient storage, retrieval, analysis, editing, updating and usage for a wide range of applications. The structures described here refer principally to polygon data.

In the Simple Polygon Data Structure, each polygon is encoded separately in terms of its constituent points without regard for any overlaps with, or adjacencies to, contiguous entities. Although this structure is very simple to encode, it results in much data redundancy as boundaries between polygons must be encoded twice. This gives rise to slivers and gaps, resulting in geometric and topological infidelity. The Point Location Dictionary Data Structure solves the geometric problem by each point being encoded only once and polygons being referenced not to the point coordinates but to the point labels. However, this structure still leaves the question of topological relations largely unaddressed (Peucker and Chrisman, 1975). The Arc/Node (or Semi-topological) Data Structure encodes some topological information. In addition to using point labels, for each arc, the polygons to its right and to its left are also specified. All this information is held by means of relational tables. Ericksen (1983) and Cromley (1984) give detailed accounts of data encoding in this structure. The Fully Topological Data Structure extends this approach to be able to handle not only neighbourhood manipulations but also infinitely nested polygons and to cross-reference attribute information among such nested polygons and line features. Software is used to build up the structure from arcs digitized in any order and in any direction, plus the associated polygon identifiers and attributes. Burrough (1986) gives a detailed account of how to build such a structure.

Obviously, considerable computing power and complex software are necessary before a Fully Topological Data Structure can be realized. However, its benefits have been well documented by Burrough (1986), Teng (1986), Dangermond (1983) and Broome (1986), amongst others. They include reduced data storage and redundancy, improved processing time for some major tasks, such as polygon overlay, and the ready availability of neighbourhood information that enables "one pass" rather than piecemeal symbolization for display purposes. The latest GISs seem to favour the data entry capabilities of the simple line/polygon structure, plus the greater manipulation flexibility and other benefits of the topological data structure, e.g. TIGRIS.

3. METHODS FOR DIGITIZING AND EDITING MAP DATA

For a production project, digital data acquisition from maps entails several steps: feasibility study and analysis, manuscript collection and preparation, digitization and editing. Marble and Lauzon (1984) have proposed a conceptual model for map data capture, in which each of these basic steps can be broken down into finer details. Of these, only digitizing and editing will be discussed here.

3.1 Methods for Map Digitization

Three methods for digitization from graphical documents are available in practice today. They are:

(a) Manual digitization,

(b) Semi-automatic digitization (line following), and

(c) Automatic digitization (raster scanning).

Manual digitization is by far the most established of these methods and involves the least capital layout. It is performed by means of a manual digitizing station which uses software to interface with the host computer. There are two modes of manual digitizing: point mode (in which the operator depresses the cursor button each time a coordinate recording is required), and stream mode (in which the coordinates are continuously output at either equal time intervals or at equal distance intervals in X and Y). In both operating modes, the operator usually enters the attribute code by means of a keyboard or other device before he starts digitizing the feature. The main advantage of manual digitizing is that it is the only viable option where budgets are limited or where the input documents are of poor quality. Also manual digitizers have a well documented history of success and operators can easily be trained to work on them.

Line following is a semi-automatic method of digitization that makes use of devices that have traditionally been called "automatic line followers". The modern devices use laser beams to track the line. The coherent light of a laser beam enables the achievement of extremely high resolutions in line sensing (Antell, 1982). When line following is successful, as in the FASTRAK digitizing system, its advantages over manual digitizing include very fast digitizing (five to 15 times faster), the recognition of junctions (nodes), which can be very useful for the generation of a topological data structure, avoidance of "windowing" problems as the whole input document can be projected onto the screen at once, and the achievement of near optimal feature representations and data volumes.

Raster scanning is a truly automatic method of digitization in which source documents are converted to digital form by a scanning/sensing device. Such a device senses the grey tone values of the analogue

data and outputs them as a series of pixels arranged in parallel scanlines. Both flatbed and drum scanners are available (Amelio, 1974; Boyle, 1979). The scanning software may enable binary scanning, recording only the presence or absence of information, or continuous tone scanning, recording a range of data values. With either method, vectorization is necessary before the data can be entered into a vector based GIS (Boyle, 1979; Peuquet, 1981). The main advantage of raster scanning is that it is a very fast means of digitizing large or dense amounts of graphic data. Tests and production experience have shown that scanning completes tasks about seven times faster than manual digitizing (Burrough, 1986; Theis, 1982; Leberl, 1982).

3.2 Editing of Digitized Map Data

Data editing may be defined as the process of detecting and correcting errors made at the various stages of data capture. Data editing also includes quality verification and later database updating. The three modes of data editing are batch editing (automatic editing), interactive editing (manual editing), and semi-automatic editing.

With batch editing, software is developed to recognize and correct specific error conditions, e.g. to detect and close unclosed polygons. The digitized data must first be displayed in order to identify the editing problems present. The errors identified are flagged and algorithms developed to automatically find and correct them throughout the data set. The main advantage of this kind of editing is that errors of the same type can be corrected in bulk, at speed and repeatedly, and also left to run during slack computing periods.

Interactive editing became possible with the development of what are generally known as CAD/CAM (Computer Aided Design and Computer Aided Manufacturing) devices. Hubbard (1985) estimates that the mapping industry stands to gain most from adoption of CAD/CAMs that could increase productivity in this area by as much as 60:1. Interactive editing allows an operator to simultaneously digitize, display and manipulate graphic data in real time by using a menu of command functions (macros) with an interactive graphics workstation. An example of such a work station is the Intergraph Corporation's INTERACT 32C dual screen colour workstation. Interactive editing can be used to advantage where error detection and correction in batch mode would require complex programming, e.g. the location and correction of "knots" in a digitized line. It also has the advantage of enabling immediate verification of the corrections made.

Semi automatic editing is probably the most efficient editing mode as it draws on the advantages of both batch and interactive editing. In this mode, the operator analyses and classifies the various errors in the displayed data into those suitable for batch editing and those to

be corrected interactively. Most CISs use this batch/interactive edit combination (Borgerding, 1982). Some systems, e.g. the U.S. Defence Mapping Agency's Lineal Input System (LIS), support two types of interactive editing in addition to batch editing (Sippel, 1975).

4. DIGITIZING MAP DATA FOR THE KANANASKIS VALLEY

Topographic features (lakes, islands, swamps, rivers, glaciers, roads etc.) were digitized from 1:50,000 NTS maps. Cadastral data were digitized from the same topographic maps and also from Range/Township maps. Surficial geology at 1:250,000 and bedrock geology at 1:1,000,000 were obtained from a surficial geology map, while soil capability for agriculture data were also collected. Manual digitiziation methods were used, no alternatives being available.

The equipment used for digitizing consisted of a Summagraphics Corporation tablet/digitizer with a 0.1 mm resolution connected to the Department's Vax 11/750 computer via a control unit. The digitizer is capable of both point mode and stream mode digitization. In order to avoid large amounts of data and subsequent smoothing operations, all digitization was performed in point mode using a 4-keyed cursor. A Princeton P8500M computer graphics terminal was used for graphical display of all points, lines and polygons as they were digitized. The digitizing software used was the Department's library program DIGIT. This is a multifunction user interactive program, which allows output either as raw digitizer coordinates or transformed map coordinates, calculated by a two-dimensional affine transformation. The hardware used for hardcopy display was the Data Technology Inc. DT3454 flatbed plotter that is connected to the Department's Vax 11/750 minicomputer, and enables a choice of four pen colours. For plotting software, a plotting program, DATAPLOT, was developed to interface with the Department's library of plotting subroutines GG-GRAPHICS.

At the end of the digitizing exercise more than 30,000 points had been digitized in a period of about 40 hours spread over one and a half months. By far the main problem encountered in the process was fatigue and loss of concentration after a certain amount of digitizing. Fatigue and stress are acknowledged problems in manual digitizing and are discussed in the literature (Rase, 1984; Allam and Wong, 1987; Burrough, 1986; Jenks, 1981). They are also often cited as major shortcomings of vector data acquisition techniques (Boyle, 1979; Leberl, 1982). At the completion of digitizing, printouts of the created data files were made and these were checked for minor errors, such as wrong pen codes or wrong attribute data. Any such errors detected, plus those flagged during digitizing, were corrected directly on the data files. Hard copy graphic plots of each of the data sets (on semitransparent paper) were then made at original scale and five times enlargement for the purpose of identifying the errors that would need to be corrected in the subsequent process of editing.

Overlaid plots of different data files were also made in order to check the fitting of interconnected features, such as rivers, lakes and glaciers. Most discrepancies were less than the map accuracy (50 m), and only became visible at the enlarged scales. Such good fits indicated accurate line following during digitizing and proper scaling and alignment. However a number of problems were identified, especially in the enlarged plots. The problems were:

(a) Some minor missed out data, mainly lines and attributes,
(b) Polygon misclosures,
(c) No information on and improper connectivity of line networks, i.e. overshoots and undershoots,
(d) No information on river flow directions,
(e) Slivers and gaps in the boundaries of adjacent polygons, especially in the dense geology and soils data, where there are many shared boundaries between polygons,
(f) Discrepancies in same feature positions at adjacent map edges,
(g) No topological information.

5. RECONSTRUCTION OF THE KANANASKIS HYDROLOGICAL NETWORK

In order to develop solutions to the problems identified above, data editing and cleaning operations were applied to the hydrological data, i.e. lakes, glaciers, rivers and swamps, for one of the topographical mapsheets, covering most of the study area. The objective of the reconstruction was to develop software that would generate from the raw data a hydrological network free of any polygon misclosures or overshoots/undershoots and in which stream flow directions could be identified. In addition, areas and perimeters/lengths for the various entities would be computed. Essentially, the operations involved polygon closure, node generation, evaluation and flagging, flow direction determination, and area and perimeter/length computation.

Polygon closure was required for lakes and glaciers in the network. Misclosures could take one of the forms shown in Figure 1. Type (a), which is the most prevalent (in one run, more than 95 percent of all misclosures were of this type), was distinguished from the other two by computing the distances: D(1) = P(1) - P(n) and D(2) = P(1) - P(n-1). For this misclosure type, D(2) > D(1), the polygon was closed simply by making P(n) = P(1). For the other two types, simply making the last point equivalent to the first could result in a "weird polygon" for type (b) and a spike for type (c). In both cases therefore closure of the polygon was accomplished by backtracking up to three points from P(n) and connecting one of these points to P(1), on the basis of the calculated angle of connection. All polygons were satisfactorily closed by this algorithm.

Node generation required that the various hydrological features be joined. A program was developed, which takes one feature segment S1 and tests it against all the other segments S2. The connection

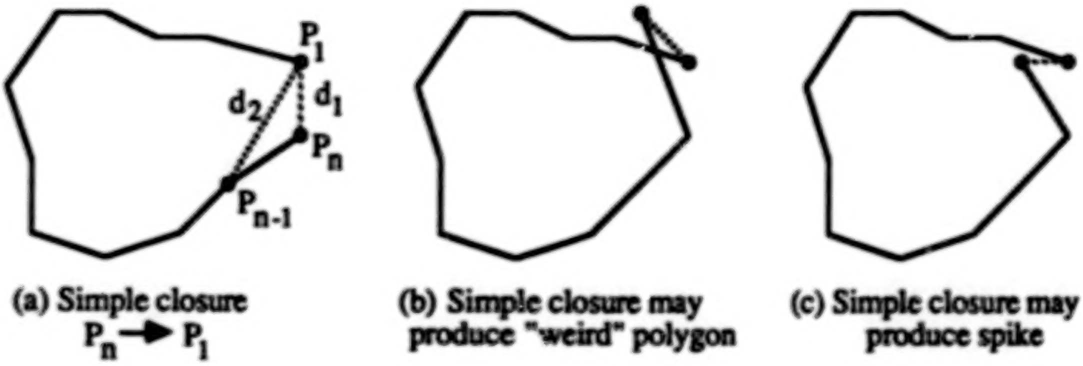

Figure 1 The three types of polygon misclosure

criterion is that either end of S1 should be within a tolerance distance, T, of a point in S2. The value of T was empirically determined as 70 m since most of the undershoots and overshoots were in the 0.5 - 1.5 mm (25 - 75 m at 1:50,000) range. Points in S2 within the tolerance distance are determined and the one closest to the seeking end of S1 is chosen for connection. To determine the actual node or connection point, two approaches were tested: a mathematical intersection approach, which calculated the intersection point of S1 and S2, and a seek and join approach, whereby the end of feature S1 is simply connected to the closest point in S2 by equating their coordinates. Connection followed a hierarchy such that all the river segments are joined first, then the lakes, swamps and glaciers.

The original program used a brute force technique and was extremely slow. It was never allowed to run to completion, but was estimated to require at least 40 hours of CPU time to finish. Intensive optimization of the program was thus embarked upon and the latest version takes about 38 minutes of CPU to complete, in which it finds 246 nodes amongst about 270 segments with about 11,000 constituent points. The most important optimization measure was to use bounding rectangles of individual features to speed up searching.

The nodes generated were physically checked for existence on the map and almost all were indeed valid connections. There were a few difficult situations, such as complex river mouths or where the entrances of two rivers to a lake are very close together. In such instances the program may fail by making a node between unconnected segments. This necessitated the deletion of some nodes and the manual correction of others. An evaluation summary for the nodes generated is given in Table 1. It is evident from the results that both approaches give node positions well within the digitized map accuracy (50 m) and both are therefore viable approaches to automated node generation. However the second method has conceptual simplicity, without the need to generate new points at the feature intersections.

	Method 1	Method 2
Nodes generated	246	246
Nodes deleted or modified	24 (10%)	14 (6%)
RMS (Northing) (m)	25.991	20.188
RMS (Easting) (m)	22.962	21.127
RMS (Position) (m)	34.681	29.222
Approximate success rate	90%	94%

Method 1 = The mathematical intersection approach
Method 2 = The seek and join approach

Table 1 Summary of the generated node evaluation

A third program was then developed to determine river flow directions and lengths. Lake, glacier and swamp areas and perimeters were also computed. The determination of flow direction, via the use of some rules of thumb on hydrological flow, was performed. These rules include, for example, flow from higher to lower elevation, flow away from glacier, flow away from open end. This proved quite successful but still left some segments undetermined, e.g. a river between two lakes. By simply identifying the node elevations for the exception cases, the flow pattern for the whole network was established. Two output files, the node segment connectivity plus the point listing files are then the final products of the project, and they are digital representations of the clean and reconstructed hydrological network. All polygons are closed and overshoots/undershoots are absent. A sample of the network after processing can be seen in Figure 2.

6. CONCLUSIONS

The aim of this study was two fold. The first was to review the problem of digital data capture and editing of map data in general, with a view to bringing to light many of the current issues in this field. This was carried out, and should provide background for anyone wishing to collect data in this way. The second, practical aim, was to digitize map data of various themes, to display them graphically, to identify the editing problems present and to develop algorithms and software in batch mode to reconstruct a hydrological network. Both of these aims were achieved and are discussed fully in Mulaku (1987).

The results showed that the main problem to expect from raw digitized network data, e.g. river or road networks, is the presence of overshoots and undershoots. For polygon data, e.g. soils, geology or cadastral lots, the two main problems to expect are polygon misclosures and slivers. The raw data displays also showed that, while the simple line/polygon data structure may be good enough for the representation of network data, serious sliver problems can arise

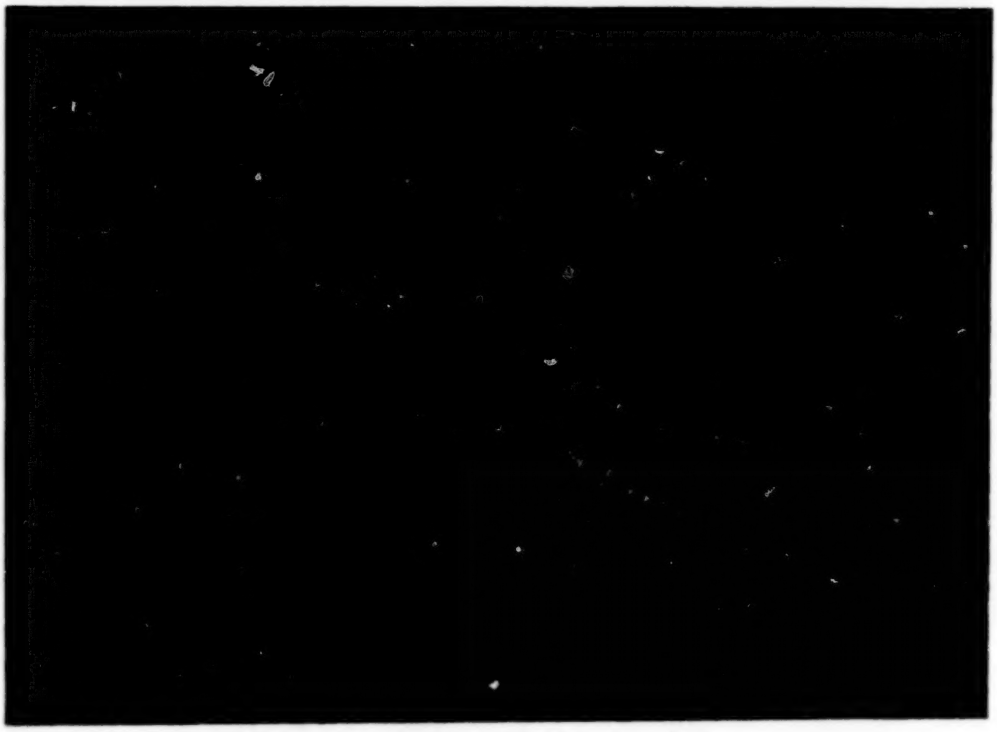

Figure 2 The hydrological network after reconstruction

with dense polygon data for which an arc/node semi-topological or fully topological structure is preferable.

In addressing the problem of reconstruction of the hydrological network, useful algorithms for polygon closure and the effective removal of overshoots and undershoots were developed, which automatically generate the nodes necessary for an arc/node data structure. It has also been demonstrated that minimal elevation information combined with heuristics, enables the flow directions of river networks to be automatically deduced. The total CPU time required to run all these programs (for this particular data set consisting of 11,000 points, 270 feature segments and 246 nodes) is less than one hour. Experience suggests that this is far less time than would be required to manually mark out the nodes on the digitized map and display and determine which way the various segments are flowing, without considering errors or the software that would still have to be developed to match the nodes at the junction points.

Thus automatic node generation, plus limited elevation data, provides a very quick and effective means of reconstructing a digitized network from "spaghetti". But it should be stressed that the development of any batch software must always allow for the possibility of failure situations that will require manual or interactive intervention.

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IMPLEMENTATION

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A CRITICAL EVALUATION OF THE PROLIFERATION OF AUTOMATED MAPPING SYSTEMS IN LOCAL GOVERNMENTS

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ABSTRACT

Many local governments in North America have acquired computer-based mapping systems over the past several years. This paper will explore this rapidly developing phenomenon and evaluate its benefits and problems. The paper will describe the technology involved and review the functional areas to which it is being applied. The benefits being derived from automation will be explored, as will the problems which have been encountered by those who have implemented systems. Finally, the paper will discuss impacts which automation is having on the organizations that are employing these techniques.

1. INTRODUCTION

Automated mapping systems, including particularly interactive graphics and Geographic Information Systems (GIS), have been proliferating in local governments over the past decade generating a veritable revolution in local government mapping operations. The number of organizations investigating and planning to acquire the technology also appears to be growing at an increasing rate. As with all segments of the computer industry, automated mapping technology is undergoing a rapid evolution in components and capabilities. This, coupled with the very extensive time required to create the initial digital cartographic base for an area, and the overall newness of the technology leaves us with an unclear picture of the true costs, benefits and impacts of map automation technology. Few installations have yet achieved anything like full production operations and all have experienced situations, both positive and negative, that had not been anticipated. Implementation has not been accomplished without problems and the organizations have had to modify their perceptions of the systems to adjust to the realities of their use. While advocates promote the tremendous potential of the systems, those who are considering the momentous move to automation have little factual information regarding actual experience on which to base their decisions. My concern is that many organizations are rushing toward acquisition without a full awareness of the realities of attaining production operation or of the experiences of those who have implemented systems. I don't wish to stop the rush, but do wish to call attention to the realities so that the systems will be acquired and implemented more effectively
This paper is an attempt to summarize the available technology, identify the functions to which it is actually being applied, and describe the benefits and problems that those who have implemented systems are experiencing. In preparing the paper, it was recognized

that little empirical data has been recorded and documentation on actual experiences is very limited. This paper is therefore both an effort to pull together some of the limited information available and a call for those in appropriate positions to conduct research on this important phenomenon in a systematic way and report the findings to those who are making decisions regarding its use.

2. DESCRIPTION OF THE SUBJECT AUTOMATED MAPPING TECHNOLOGY

2.1 Overview

In the mid-1970s commercial firms began marketing what came to be known as turnkey interactive graphics systems, which started the movement to automated mapping in local governments. The systems were typically based on a dedicated minicomputer supporting an integrated complement of hardware and software components. More recently geographic information processing systems of similar concept have also become available. The availability of these relatively low cost systems has made it possible for local governments to automate mapping and geographic information processing operatings in a cost effective manner.

One of the basic characteristics of these systems is their user friendliness. They have been designed and developed to allow those with little or no computer expertise to operate them directly with minimal technical assistance. This concept has been important to the acceptance and usefulness of the systems.

In operation, the systems include hardware, software, and data base components along with personnel, supporting procedures, documentation and other elements.

2.2 Hardware

The hardware component of an automated mapping or geographic information is typically built around a mini or supermini computer, though mainframe and recently micro-based systems are also available. The configuration includes relatively large disk storage capacity, magnetic tape unit(s), a console and other common computer peripheral devices. Mapping also requires special graphic devices for the input of graphic data (digitizers) and for output on temporary displays (graphic CRTs) and permanent copy (plotters).

The systems focus on workstations through which the primary operator functions are performed. A workstation consists of one or more high-resolution graphic CRTs on which maps are displayed, a digitizing table for conversion of map images to digital form, a keyboard for entering data and commands, and usually a menu area or device for selecting commands for system operation. The operator enters map data by tracing map features on the digitizing table, views maps on the

graphic display device, and interacts with the displays through the menu and cursor.

Permanent graphic output is typically produced on either a pen or electrostatic plotter, though other devices for making slides, microfilm or other display media may be used. The plotting is controlled by the computer using the map data base and operator instructions specifying features, scale and so forth.

2.3 Software

The hardware devices are controlled by a comprehensive repertoire of software, including an operating system, graphics package, data base management system, macro language, FORTRAN and/or other compiler, analytic programs, and utilities. These components are integrated into a system that is typically very easy to operate with most commands being issued interactively by means of menus (Kevany 1983).

The operating system is provided by the computer vendor and controls the basic computer operations. The graphics software is used to enter, store, and display graphic images and to control the production of permanent media maps. The data base management system stores the non-graphic attribute data in a manner that allows for linkage with related graphic elements and for efficient retrieval and reporting. This component also allows the operator to specify report formats and produces tabular reports in accordance with those specifications. The MACRO language allows an installation to tailor the system by linking basic functions to perform a sequence of steps in a repetitively used procedure. Analytical programs are provided, particularly in the GIS systems, to perform standard spatial analysis functions such as polygon overlaying and area and distance calculation. Finally, the software configuration will include an application programming language that allows the system user to develop specific processes within the overall operation of the mapping system.

Each of these software components is integrated with the others and with each of the hardware devices to form a complete system.

2.4 Data Base

The automated mapping system may consist of a graphic mapping data base exclusively, or it may also include a non-graphic attribute data base. In the graphic portion of the data base, the map feature elements are usually stored in some type of layering scheme so that combinations of similar features are stored as essentially overlays to a base. This allows various combinations of features to be displayed or plotted by selecting or turning on or off the various layers in the data base. The elements are stored in the base in a structure that will facilitate their easy selection and display. Most systems allow for all map sheets of an area to be merged to form a continuous digital map of the

area. Individual entities are generally assigned an identifier that allows them to be linked to their attribute data elements. The attribute portion of the data base contains alphanumeric data and codes describing the characteristics of the entities represented by the graphic elements. The attribute data are stored in a data base structure (e.g., relational, hierarchical, etc.) in accordance with a schema defined by the user of the system. This schema defines the relationships that exist between and among sets of data and will facilitate retrieval of data by the system.

3. APPLICATIONS OF AUTOMATED MAPPING

3.1 Summary of Organizations

Numerous local governments across the United States and Canada, as well as much of the rest of the world, have adopted automated mapping procedures and have acquired automated mapping systems. Though a minimum size is generally considered necessary to support a sophisticated mapping system, jurisdictions of a wide range of sizes have acquired systems. Within the locale the system may be operated by a consortium of organizations or of functional departments within an organization, by an individual department as a service to others, or by an individual department for its own purpose. Table 1 presents a summary listing of organizations that are now using automated mapping systems. As can be seen, the installations are scattered all over the continent and are addressing numerous application areas.

3.2 Functional Areas

Automated mapping systems are being applied to a wide variety of individual applications. Experience has shown that computer graphics has benefits in virtually all functions of city government (Gschwind 1982). In general the applications can be grouped into the following five classes.

1) Municipal Mapping--Production maintenance of base and overlay map features.

2) Cadastral Mapping--Production maintenance of parcel ownership and tax maps.

3) Utility and Infrastructure Mapping and Management--Production maintenance of public utility facility maps and management of facility information.

4) Land Use Planning--Performance of spatial analyses and production of thematic maps.

5) Natural Resource Evaluation--Storage of physical characteristics and related map boundaries, performance of polygon overlaying,

Table 1. Sample of Automated Mapping System Sites

SITE	TYPE	APPLICATION	STATUS
Anchorage, AK	GIS	Land Use Planning	Mature
		Public Works	Mid
Bellevue, WA	Graphics	Municipal Mapping	Mature
Lane County, OR	Graphics	County Mapping	Mature
		Land Use Planning	
No. Slope Borrough, AK	GIS	Resource Evaluation	Mature
San Jose, CA	Graphics	County Mapping	Mature
		Sewer Mapping	
		Utility Mapping	
Bay Area SIS	GIS	Regional Planning	Mature
Los Angeles (City), CA	Graphics	Engineering Mapping	Mid
	GIS	City Planning	Mid
Los Angeles (Co.), CA	Graphics	Road Mapping	Mid
San Diego Comprehensive Planning Organization	GIS	Regional Planning	Mid
Clark County, NV	GIS	Land Use Planning	Mid
Long Beach, CA	Graphics	Municipal Mapping	Mid
Wyondotte Co., KS	Graphics	Paracel Mapping	Mature
		Land Use Planning	
Hennipin Co., MN	Graphics	County Mapping	Mature
		Land Use Planning	
Minnesota	GIS	Resource Evaluation	Mature
		Land Use Planning	
Chicago, IL	Graphics	Municipal Mapping	Mature
Milwaukee, WI	Graphics	Municipal Mapping	Mature
Houston, TX	Graphics	Municipal Mapping	Mature
		Utility Mapping	
Austin, TX	Graphics	Municipal Mapping	Mature
Atlanta, GA	Graphics	Public Works	Mid
New York City, NY	Graphics	Land Use Planning	Mature
Salem, OR	Graphics	Municipal Mapping	Mid
Forsyth Co., NC	Graphics	Parcel Mapping	Mature
San Bernardino Co., CA	Graphics	Parcel Mapping	Mature
Virginia Beach, VA	Graphics	Municipal Mapping	Mature
Pinellas Co., FL	Graphics	Parcel Mapping	Mature
Burnaby, BC	Graphics	Base, Parcel, and Utility Mapping	Mature
Calgary, Alberta	Graphics	Municipal Mapping	Mature
Edmonton, Alberta	Graphics	Municipal and Utility Planning	Mature
Vancouver, BC	Graphics	Municipal Mapping	Mature
Knox Co., TN	GIS	County Mapping	New
Alachua Co., TN	GIS	County Mapping	New
Albuquerque, NM	GIS	County Mapping	New

spatial analysis, and production of thematic maps.

The first three classes began initially as essentially drafting operations, but are evolving increasingly into combined map maintenance and attribute processing applications as the capabilities and understanding of the systems are growing. In each of these classes an initial digital cartographic file of selected base and overlay features is created from one or more manual sources, including aerial photography, existing maps, legal descriptions, and field collection. Once the initial file is created, procedures are developed and implemented to continually update the features, generally from administrative operations, and to produce and distribute standard and special map products. The earlier mapping applications are being expanded to include spatial analyses and thematic mapping as attribute data bases are linked to their graphic representations.

The utility and infrastructure applications may include engineering design and plan drafting operations along with map maintenance and production. Network analyses and facility management are also important to utility applications.

The land use planning and natural resource evaluation applications generally have less interactive digitizing and drafting than the prior classes, but have greater attribute storage and processing, spatial analysis, and thematic mapping use. In these applications the physical (soil, slope, etc.) natural (vegetation, biota, etc.), cultural (demographic, economic, etc.) and administrative features are digitized and registered to a common control. The attribute characteristics are entered into the related attribute portion of the data base. The system is used to compare conditions through polygon overlaying, to perform other spatial analyses and produce thematic maps and reports of resulting conditions.

4. BENEFITS FROM AUTOMATED MAPPING

Since most systems have not reached operational maturity, their true benefits are still open to verification. Benefits in the areas of improved drafter productivity, reduction in redundancy, improved timeliness of map updates, greater flexibility in available products, and others have been experienced for map automation. An additional major benefit has emerged as the systems became more sophisticated. The tremendous retrieval, analysis, and display opportunities that have been opened through the linkage of the map graphic images with their related attribute values in an integrated data base are proving more important than the drafting capabilities in most installations.

4.1 Cost Savings and Avoidance

Cost savings will be achieved in part through the improved productivity of automated mapping systems. Productivity improvements result

from two primary areas: (1) the actual speed with which a system operator can retrieve and display in formation and produce the necessary maps using the capabilities of the computer, and (2) the functions that the computer can perform with minimum operator intervention.

True productivity values, however, are difficult to measure. Ratios of 3:1 to 8:1 have been claimed based on production tests. However, actual productivity in a local government is much more difficult to measure. Typically the cartographic staff spends a significant portion of its time researching changes to be made or features to be drafted, responding to inquiries and performing other tasks which are not directly affecting by computer system capabilities. So, while map drafting may be improved by a large ratio, actual improvement in organizational productivity may be much less. A few estimates have been made of actual production operations, but not enough to provide a reliable factor.

The area with the greatest potential for cost savings or cost avoidance in mapping among local governments appears to be reduction or elimination of redunancy. In most organizations, multiple departments are maintaining and updating maps. New development may be drafted onto a dozen or more map sets in different organizations. With the use of an automated system, this may be reduced to a single update task with the resulting updated features being made available to all organizations through the computer system. The potential for saving here is great.

Available information on cost savings shows that those with systems are positive about the potential. Where systems have had to be rejustified after a few years of use, they have been defended successfully. Though specific data is rarely available, the information that is available is generally positive. San Jose, California, for example, has found that experience to date does indicate that the machine mapping of the City's myriad maps was shown to result in a significant long-term savings over manual methods (Zouzoulas 1983).

4.2 Timeliness

Another major benefit area from automated mapping systems is timeliness. Since computer systems are capable of storing, retrieving, and displaying data at electronic speed, automated mapping systems are assumed to facilitate the timely delivery of map products and information. The results of actual operation bear out this benefit in more than just system speed. It is true that a computer system can drive a plotter to produce a high-quality map product in a fraction of the time required for manual drafting. This speed is quite valuable in map production operations and when the City Manager needs a map quickly for a citizens meeting or other purpose. The speed of production, of course, must be tempered by the time required to digitize the source materials and their various updates. Still, automated production is providing significantly faster than manual.

While maps can be updated more quickly with an automated system than manually, the true value of timeliness really begins here. While in a manual system, a new development might have to be drafted separately onto several individual maps and various base or overlay features or annotation might have to be adjusted on each to accommodate the update, in an automated system, once the update is entered into the data base it is instantly available to all system users without any re-entry by others. This means that new parcels, streets, and water lines that traditionally took months to be added to all the various maps throughout a local government are now being made available to all departments within a week or two (actual update time itself may be only minutes or a few hours).

Timeliness in support of decision making is a valuable benefit of automation as well. The ability to retrieve and analyze data geographically and to produce easily comprehended graphic displays has proven very valuable. The City of Milwaukee, for example, estimates it saved $100,000 during a snow emergency through use of its system to support decisions on allocation of snow plowing equipment.

In the area of the GIS, the timeliness is reflected mainly in the time required to perform an analysis and arrive at a decision. Where planners and engineers traditionally have spent weeks and months acquiring and organizing data for an analysis, and then often had little time left to perform a thorough analysis, they can now generate reports and maps within hours giving a timely response to a request or question.

The time required to match attribute characteristics with geographic locations and to list, plot, or display the results is generally extensive in a manual operation. If a large number of entities or incidents is involved, it might prove to be impractical. An automated system can perform such a function in minutes or even seconds.

Experience with automated mapping systems has verified the benefits to be derived from their timeliness once the data base is available.

4.3 Flexibility

An important characteristic of a computer mapping system is its flexibility. Once the digital map data base is created, and of course maintained, it can be output in virtually any format, area or combination of features desired by the operator. The system stores basic information and allows referral by geographic area, combination of features, or attribute value (e.g., type, size, value, etc.) and display in an almost unlimited array of scale, size, format, color combinations, and so forth specified by the operator. The resulting maps can be produced on the graphic display screen, the plotter, or other permanent output devices.

Flexibility is reflected in two production areas in actual practice--a wider range of standard products tailored to each organization's individual requirements and great latitude in display and production for individuals who operate the system to produce ad-hoc products. Attribute processing is also important in achieving flexibility benefits. It adds another dimension to the system capability and to the flexibility that the system provides. It means that attribute values and geographic locations can be considered together in generating a display or performing spatial analyses.

The range of flexible applications of these systems seems boundless. Numerous combinations of polygons and attribute values have been overlaid to analyze relationships and produce maps of resulting conditions. The Alaska Department of Natural Resources has used its GIS and data base of physical and environmental conditions to evaluate the impacts of energy extraction activities, to determine prime development locations and to select routes for roads through the wilderness. In short time periods it has recombined various sets of characteristics, overlaying one on the other and producing numerous maps of basic conditions and combinations of characteristics, highlighting important situations (either negative in the case of environmental impacts or positive in the case of development suitability).

Another aspect of the flexibility in automated systems that has proven valuable is the ease with which they accept, as input, source maps of varying scales or format. Combining maps of differing scales has traditionally meant photographic reduction and/or manual scaling and adjustment. The digitizing procedures in an automated system on the other hand allows the operator to specify the scale and orientation of each map being digitized. The system then adjusts its interpretation of digitizer input and transforms the data from each of the source documents into common measurement units for storage in the data base. Differences in format can be accommodated flexibly as well. The combination of single line and double line street maps would conventionally require some form of redrafting. In the automated system, however, either can be digitized and system capabilities can be used to produce parallel street edges from a single line or vice versa with a minimum of effort.

5. CONSTRAINTS AND PROBLEMS

Implementation of automated mapping, as with virtually all new technology, has not occurred without problems and the reality of its use includes some significant constraints.

5.1 Initial Data Base Development

The single most serious constraint upon the implementation and use of an automated mapping system is the effort required to develop the initial digital cartographic data base. Conversion of existing maps to

digital form or creation of digital maps from survey, coordinate or legal descriptions is time consuming and costly. In virtually all early casaes reported, it has exceeded estimates. Numerous techniques and technologies, including automated scanning, have been applied in various locales with the consistent result that data conversion is still time consuming and costly. Part of the problem rests with the sheer magnitude of the data that reside on the maps of a local government, part rests with the level of precision and accuracy required to satisfy the system user's requirements and part is a result of the quality and availability of source materials. In fact, in some cases the motivation for automation has been to develop a quality map base, and in these cases the double task of remapping and conversion to automation has bveen particularly costly. As an example, the City of Houston, Texas, spent approximately $10 million over 6 years to have a contractor remap and digitize the city's features.

Estimating data conversion costs and time was difficult among early installations since so little data and experience are available. The City of Milwaukee, one of the earliest automated municipal mapping systems, conducted a pilot project in which it was estimated that each map sheet would require an average of 45 hours for digitizing. The actual project costs however were almost double the estimate, or 80 hours. Even at the midpoint in actual conversion, the estimates were well below the $826,000 and 7 years that were finally required for digitizing the 160,000 parcels and other features of the city. (Full system development costs were $2 million.) Such long conversion periods are typical as reflected by San Jose, California, which took about 4 years digitizing maps of the sewer system and Virginia Beach, Virginia, which required 8 years to digitize its map using an early and relatively small system.

This timing problem has led to a trend toward contracting with service mapping firms for data base development to speed the process. Where funds are available, this has been a helpful solution to the delay in reaching productivity on operations. It has been noted, however, that too much dependence on contractor support may create problems of its own. Use of service bureaus has grown dramatically. Along with the speed of conversion and reduction of impact on local staff, the cost estimation process has improved dramatically also. Reliable estimates can be obtained relatively easily today using the costs of service bureaus as a basis.

Problems related to the long timeframe required for data base establishment also arise in the form of political or managerial impatience which occurs while awaiting production visibility. Several system managers have been required to rejustify systems during data development when politicians or managers worried about the wisdom of the investment. In at least one case, a system was almost removed due to lack of evidence of productivity while involved in the extensive data development process.

A successful approach to dealing with this situation that has emerged

is the quick development of a data base at a general level that can be used for immediate application of the system. Cities such as Milwaukee and San Jose have created DIME-type files to produce thematic maps and perform planning and management analyses quickly. These applications were developed and operated concurrently with the major detailed data base digitizing.

5.2 Organizational Problems

Some organizations have experienced conflicts between and among departments with an interest in the automated system. Since the system operates on a computer, the Data Processing Department feels it should have prime responsibility, while the Public Works Department or Surveyor's Office claims prime authority as the chief mapping organization. The Tax Assessor too claims control in some cases and in others the organizer of a combined effort such as the Planning Department claims responsibility. In some cases these conflicts have delayed or hindered the success of the system. They have often led to the formation of a system user's committee to share responsibility.

Conflicts have also arisen between and among map experts from various departments as mapping activities are merged into the central automated system. In these cases disputes over symbology, procedures, accuracy, or product formats have arisen. Issues that were overlooked in separate mapping organizations or actually led to the formation of separate groups now surface as the computer system is designed to service multiple purposes to achieve cost effectiveness.

Data base maintenance and quality control are particularly subject to dispute, though in some cases it is because multiple organizations wish control while in others it is because no one wants to accept responsibility.

5.3 Obsolescence

As a product of modern computer technology, automated mapping systems suffer from the rapid evolution that is the nature of the industry. Improvements in hardware and software take place at an alarming rate, far outstripping the ability of the persons involved to keep up and continue to exploit the latest development to its fullest. While the vendors do attempt to hold products and software versions in operation for as long as is practical, they must also keep up with a highly competitive environment and so must continually upgrade and modify. Software improvements are made in the form of new releases of the package that the customer has purchased. With each new release, the customer must, at a minimum, install and understand the changes. Periodically, major version changes occur requiring more effort, including perhaps reformatting of files and retraining operators. At infrequent intervals, though often before the full economic life cycle of the system has been achieved, hardware must be upgraded or converted

to keep up with the demands of new software. This obsolescence means that not only may an organization wish to upgrade to obtain the new improved capabilities, but at times it may be required to upgrade because the vendor has issued notice that he will no longer support an outdated version or configuration.

Matched with the long lead time required to achieve full production, this obsolescence may cause additional problems where an organization must upgrade a configuration even before it has achieved operational status. In the local government environment, this is obviously a politically dangerous situation.

5.4 Personnel Impacts

Automation of mapping operations impacts cartographic personnel in several ways. Initially there is a psychological or emotional impact in which some persons view automation as a major career opportunity to move into the latest technology while others view it as a threat to job security and resist its adoption.

Transition to automation requires training which most persons are able to master, though a few just do not adapt. It also often involves a period of additional work to accommodate training and data conversion while continuing to maintain the manually prepared maps. This is often a period of turmoil and, if not managed properly, can cause serious personnel problems.

The creativity of individuals may be restrained by the generally standardized approach to automation. Cartographic license may be curtailed, causing problems for some individuals. Most persons involved become operators of workstations, which is challenging to some, though it is generally performed in accordance with standard procedures. The opportunity to exploit the system's capabilities, however, offers a challenge of a different type to many persons. Given a system with adequate graphic flexibility, cartographic design expertise is applied at the project design and setup stage (Moore 1983), giving creative persons an opportunity to express their talents. The concensus of system users and managers seems to be that people, not the technology, will determine the success of automated mapping (Gschwind 1982) and so the personnel impacts of automation must be dealt with carefully.

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TOWNSHIP TO STATE AND VICE-VERSA
THE POTENTIAL MINNESOTA GIS HIERARCHY

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ABSTRACT

The Land Management Information Center (LMIC) of the Minnesota State Planning Agency plans to support broad applications of GIS technology. Recent development of software which runs on personal computers which is compatible with their minicomputer system will help extend the technology throughout the state. Several problems are being dealt with in anticipation of this new level of use. Problems involve 1) training system support, 2) data development and dissemination, and 3) accuracy and reliability of data, particularly for larger scale, local applications. Strategies are being implemented to address each of these issues.

The new software, EPPL7, is inexpensive or free to certain state agencies. A course has been taught to state foresters familiar with PC DOS. Their high motivation was due to availability of forest inventory data in grid cell formats down to 5 meters.

Addressing the need for updated, high resolution data sets, may involve sharing training and data evaluation with township governments. They can correct data which is obsolete and use it in concert with other newer data of local relevance provided by the state. Satellite imagery may also play a role in providing higher resolution coverages than the current 40 acre data sets.

Accuracy is being addressed by replacing inaccurate data sets as better information becomes available. Re-registration of the whole data base to UTM coordinates is also being done.

By catering to a more distributive GIS environment, LMIC hopes to create a two way flow. In this way the state agency may be better able to support the highest levels of decision making with data validated at the grassroots level.

INTRODUCTION

Minnesota has benefitted from a strong central G.I.S. facility for over 15 years. Currently, the Planning Information Center (PIC) of the State Planning Agency houses a powerful system built around a PRIME 9955 II super-mini computer and a diverse selection of commercial and in-house software. The major software systems are Arc/Info by E.S.R.I. of Redlands, California, and EPPL6, a grid cell product developed at PIC. An extensive range of peripheral devices and a large array of utility software completes the system. Over the years the Center has completed numerous projects for clients throughout the state and, in fact, outside the boundary of Minnesota as well. The centralized function has been a necessary inconvenience for outstate users who, of necessity, worked through PIC staffers to apply G.I.S. techniques to their local problems. Centralization was necessary in order to maintain secure funding from the legislature, to serve the vast majority of users who were in the Twin Cities area, and because computerization had not developed viable alternatives for effective distributive use of large databases.

This paper describes the opportunity that currently exists for a symbiotic relationship to develop between the central site and numerous smaller facilities, potentially down to the township level. Over the past two years, the Planning Information Center has authored EPPL7, a grid cell G.I.S. that runs on IBM-PC's and compatibles. These machines are available in many of the minor civil divisions of Minnesota and in regional offices of state agencies. With the addition of better color displays, to take advantage of the EPPL7 graphics, hundreds of offices throughout the state can now apply G.I.S. techniques without extensive central staff support.

CURRENT USERS AND EPPL7

Regular users of PIC currently include the Minnesota Department of Natural Resources (DNR), the Minnesota Pollution Control Agency (PCA), the United States Fish and Wildlife Service, the Twin Cities Metro Council, the Center for Urban and Regional Analysis (CURA) of the University of Minnesota, and several other centers and agencies. All of these users are currently working through timeshare ports or by sending staff members to PIC as needed. Regional development commissions (RDC'S) throughout the state and a few counties are also significant occasional users. The DNR, PCA, and the RDC'S have offices spread widely over the state and can gain considerable benefits from operating in-house G.I.S. projects using downloaded portions of the state-wide data bases. Smaller governmental units may also find EPPL7 of use as higher resolution data bases are developed. Within the larger agencies, there is a sufficient number of interested potential users to make adoption of EPPL7 a near certainty. At the local level, in municipalities and townships there is less interest, in part because of lack of education in the G.I.S. area, and because there is so little data currently available in small grid cells.

The Planning Information Center plans to support the broadest possible application of G.I.S. technology throughout Minnesota. Toward this end, they anticipate their role changing to a heavier emphasis on archiving and distributing data and in training new users. It may be that developing new users creates more work for the center in data development and in dealing with more sophisticated applications that have exceeded the grasp of either the PC's or the PC users. Several problems, or opportunities, are being dealt with in anticipation of this new level of use. Problems fall into three areas; 1) training new users; 2) data development and dissemination; and 3) accuracy and reliability of data, particularly for larger scale, local problems.

TRAINING NEW USERS

Training of new users has to accomplish several goals in order to be effective. It must develop knowledge of the limitations as well as the strengths of the technology, otherwise the user will fail and blame the system. Second, it should foster a co-dependence between PIC and the trainees so that data flows both ways; enhancing the state held archives and supporting data development at the local levels. Third, training should instill a skill level that will enable the user to execute most tasks that the package is intended to perform.

Because the computer can do it does not imply that it should be done. Among the most serious limitations which must be presented are those associated with rescaling data sets. Some knowledge of the history of each attribute file must be known before they are used in combination with other files. The state data bases range in resolution from square mile grid cells to 5 meter cells. Reliability also varies from file to file and in some cases it is variable between regions of the state. Of course, having been grown on legislative funding, some of the data bases suffer from insufficient maintenance, and are slightly or seriously out of date. New users must have a way to estimate the reliability of the current state-wide data are primarily in 40 acre grid cells which are being converted to Universal Transverse Mercator coordinates. Soils data are currently being scanned in by counties in 5 meter grid cells. Thematic Mapper imagery with 30 meter resolution will likely be classified into landcover classes in the next year or two. These efforts are motivated by the ability of current technology to accomodate larger data volumes and by the desire of PIC to provide information of use to smaller planning units, and by the availability of current data in these formats.

Regional offices of the DNR are equipped with PC-XT's and need only to add EGA cards and color monitors to use most of the power of EPPL7. Because the personnel are familiar with their machines and disk operating systems, it has been relatively easy to teach them the basics of the system. A three day course was taught to D.N.R. forestry staff who were PC users. The equivalent of one day was spent on basic G.I.S. considerations. The other days were used to introduce EPPL commands and the other parts of the software system through a series of simulations of progressively greater difficulty. The students were highly motivated because there is an extensive forestry data base available for all State lands. The inventory, loaded onto the PRIME system through Arc/Info, is easily converted into raster format for EPPL7 processing. The Minnesota D.N.R. is divided into branches such as waters, wildlife, and parks. Because the forestry data base is extensive and detailed, these other divisions are also interested in applying G.I.S. solutions to their problems. They are particularly interested in enhancing the forest inventory data with satellite imagery to identify smaller parcels than the five acre minimum presently recorded.

If a strong data base motivates the need for training and adoption of G.I.S. then the next group to be served should be soil conservation personnel in the recently surveyed counties of Minnesota. Numerous of these counties have had their maps scanned into Arc/Info and raster formats. These 5 meter grid cell coverages are potentially powerful tools for numerous uses. Of course, this data combined with forest inventory data is very appealing to the entire resource management community.

Soil and Water Conservation Districts need to be able to address problems at the township level. EPPL7 with county soils data installed as 5 meter grid cells is sufficiently detailed for local applications. There are over 3,000,000 such grid cells in a township of 36 square miles. This approaches the limit of a PC for effectively fast processing. EPPL7 has processed and displayed an entire county of about 12,000 rows by 17,000 columns on a PC/AT. The process to build the data into a displayable file took 15 hours. Most manipulations at the township level take a matter of minutes rather than hours. More homogeneous data can be analyzed faster than the extremely heterogeneous soils data. In fact, through its excellent file compression, the five meter files of homogeneous coverages require relatively little storage space. Over three million cells of 5 meter land use coverage for a township compressed down to 170 kilobytes.

Because of the obvious need for this technology to make use of these new data bases, additional training sessions are anticipated and may be offered on a regular basis. Through its DISPLAY program, EPPL7 can serve as its own tutor. This menu driven module can run log files of mixed map and text displays to demonstrate the products of command strings. Self driven demonstrations are already developed to show a range of potential applications of the package. With some additional work, these can be made into instructional modules. An existing lesson on the processes of combining forest inventory data with classified Thematic Mapper data has drawn consistent interest as it shows step-by-step the relationships between file types, command strings, and products.

COOPERATIVE DATABASE MANAGEMENT

An opportunity exists for a healthy symbiotic relationship to develop between townships and the county, regional, and state level planning interests. EPPL7 has potential utility as a tool for township administration. It can be used as a "map cabinet" or as an analytical tool depending on the sophistication of the local user. Minnesota currently suffers from an outdated rural land use data base. An option for updating this coverage is being explored in which township boards will evaluate the obsolete coverage and edit it.

The editing may be manual or within EPPL7. Interest in this process is stimulated by the recently inacted local water management planning legislation through which counties may receive funding from the state to gather information and produce policy documents to protect or improve their water resources. Since surficial hydrologic models are dependent on land cover variables, it is foolhardy to accept funding under this program without expecting to update the data. In Beltrami County the organization

of township officials have expressed interest in cooperating in this endeavor. Through this process, it is hoped that not only will the coverage be improved, but at the same time new users for the G.I.S. will be cultivated. Since local initiative is required to create the rasterized soils data, it is hoped that having involved the townships in creating one coverage, they may be inclined to support development of more. Thus, by updating landuse on a cooperative basis, support for procuring the soils data may be strengthened. Obviously, surface water modelling without soils data will be prone to failure just as it is without current landuse.

The Planning Information Center is interested in sharing data with local users that might provide updating. PIC could provide a base map of existing landuse data, vintage 1969, and replace the old coverage with the new as it became available. A spotty, updated coverage might result, however, it would probably address the areas in which significant change has taken place and "grandfather in" the less change-prone areas. A similar process is currently taking place within the D.N.R. Division of Forestry with district foresters sending hardcopy map updates to maintain accuracy of their inventory coverage on the G.I.S.

The legacy of a long established Geographic Information System includes a strong experience base from which to approach current problems. Unfortunately, it also brings data of various ages and degrees of accuracy to bear on those problems. Minnesota, perhaps more than most states has good reasons to study and salvage its data bases. The software systems which the state has acquired or developed to manipulate the data are extremely effective and durable. Also, many of the data sets are quite current. Two problems of accuracy are currently being dealt with. The first is simple obsolescence. Landuse is the coverage in greatest need of updating and steps are underway to address this need; either through grassroots cooperation as discussed above, or through remote sensing. Other coverages, such as soils, or geomorphic regions were installed from very low resolution sources. Soils data are slowly being replaced with current data as it becomes available. More recent surficial geology is available than when the original data were loaded in and will be installed. This sort of obsolescence is readily addressed as more current information becomes available. Positional accuracy is a tougher nut to crack. Part of the Minnesota legacy is the Minnesota Land Management Information System 40 Acre (MLMIS40) data files. There are about 1.3 million forty acre parcels in the state which were the units by which most of the data in the state system were recorded. For expediency and cost effectiveness, the original data sets were built with the assumption that sections were square miles, townships were exactly six miles on each side, and forties were all the same size. A major effort has been made to redefine the forties into UTM coordinates with control derived from USGS quadrangle section corners. Accuracy in this conversion seems to be within about 25 feet in most cases when assessed against state plane coordinates provided by other agencies in the state. Efforts to determine parameters of spatial accuracy and data reliability become critical when the potential for local users at the county and township levels is considered.

Just as the foresters and soils people are strong potential users of the State Planning software because good data sets exist, so the county and township officials could become strong advocates if the less specialized data sets can be made current and of higher resolution. Establishing standard assessments of accuracy and reliability is a first step in addressing these problems.

HARDWARE HIERARCHY?

The high resolution, 5 meter, data sets obviously appeal to those faced with local problems. Hundred meter data might be more appropriate for regional, or county planning needs. The availability of these large volumes of data at each level offsets the potential hardware heirarchy between counties and townships since a township might process as much 5 meter data as a county would of 100 meter resolution. In either case, the state agency might be the only level needing to have all resolutions, probably stored as ARC/INFO files, permanently available. For most envisioned township applications a "PC" with a 20 to 40 megabyte hard disk will serve well. To access high resolution data sets such as 5 meter soils data at the county level requires greatly extended memory, probably of the cartridge type and a faster machine. Storage of comprehensive statewide coverage need not be on disk except in low resolution formats. Counties might also benefit from having selected, low resolution coverages for themselves and adjacent counties by which to gain a more regional perspective. The Planning Information Center will provide subsets of all their data sets to local users in EPPL7 format for very nominal fees of about $150 per county. It is hoped that such broad distribution will enable Geographic Information Systems to become part of the routine administration of land and water resources throughout the state.

CONCLUSION

PIC hopes to provide the critical overall archival role and to provide hardware and software support to the more sophisticated users who need more elaborate output devices, or who need the expanded computing power of the largest center. By supporting the local development of data sets, it is hoped that the state level archives will remain more current and therefore more useful. By supporting all levels of the potential GIS hierarchy, the State Planning Agency can provide an effective service while continuing to be the major source of information for the highest levels of decision making.

The Public Land Survey System: Linking GIS Technology to LIS Applications

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ABSTRACT

Geographic Information System (GIS) technology automates the collection, management and analysis of spatially related data, providing it in formats which are useful decisionmaking tools. The key element which allows GIS technology to provide the capabilities of a Land Information System (LIS), or multipurpose cadastre, is the cadastral parcel.

The Public Land Survey System provides this parcel information for a large portion of the United States, presently in the form of survey plats. This paper describes the Bureau of Land Management's development and implementation of the Public Land Survey System/Geographic Coordinate Data Base (PLSS/GCDB). The PLSS/GCDB will provide the digital data required to graphically represent parcel boundaries as shown on official cadastral survey plats, the necessary framework for an automated LIS.

1. INTRODUCTION

Geographic Information System (GIS) technology automates the collection, management and analysis of spatially related data. It allows us to overlay thematic layers of information in formats which provide analysis tools useful for decisionmaking. These tools include statistical analysis and map products which, in the past, were prepared manually.

"Land" literally means a portion of the earth's solid surface, with all its natural resources and anything constructed on it, distinguishable by boundaries and ownership. Land managers, whether the owner of a one-acre residential lot or of vast areas, need to know the extent and location of the land which they are to manage. By incorporating the legal parcel, GIS technology can be used for Land Information System (LIS) applications.

2. THE PUBLIC LAND SURVEY SYSTEM OF THE UNITED STATES

Surveys under the Public Land Survey System (PLSS) were initiated more than 200 years ago, in 1785. These Cadastral Surveys create, mark and define boundaries of tracts of land. The PLSS was designed with significant foresight to provide us with an efficient method of uniquely describing individual parcels of land.

The PLSS is based on a rectangular system of surveys. Surveys commence from 36 Initial Points throughout the western United States (including Alaska). From these Initial Points, Base Lines are run east and west, and Principal Meridians are run north and south. This is the framework for townships which are counted north and south from the Base Line, east and west from the Principal Meridian. The townships are nominally 6 miles on a side, and are divided into 36 sections which are nominally one mile square. The sections are further subdivided into sixteen "aliquot parts."

This system of survey provides a unique identification of a parcel of land by its location within a township which is referenced to the appropriate Principal Meridian and the State in which it is located. This unique identification, along with a standard method of survey, easily lends itself to automation.

There are also Special Surveys in the PLSS. These include such parcels as Land Grants, Homestead Entries, Mineral Surveys, irregular tracts and lots, among others. These are special types of survey which generally conformed to the configuration of resources such as arable farmland, mineral deposits and natural topological features. They do not conform to the rectangular system of surveys, but can also be uniquely identified.

The lines that are surveyed, established, retraced or resurveyed are represented on official Cadastral Survey plats, showing the direction and length of each line. The plat is accompanied by the official field notes which contain the written record of the survey, including a description of the lines and corners of the survey and the procedures by which they were established or reestablished.

3. THE PLSS/GEOGRAPHIC COORDINATE DATA BASE

The Bureau of Land Management (BLM) is responsible for the management of more than 300 million acres of public lands. In order to effectively manage multiple resources, maps are produced to display the resource information. The land boundaries must be shown on these maps. Traditionally, the land boundaries for these map products were manually generated, based on the information shown on the official Cadastral Survey plats, or in other words, a duplication of effort.

In recent years, automated plat drafting systems have been developed which provide the special capabilities needed in the preparation of survey plats. These plat drafting systems provide a graphic representation of the lines that were surveyed, established, retraced or resurveyed. They also provide the capability to display and plot bearing and distance measurements, labels and text, symbols and other plat requirements.

The graphic portrayal of the cadastral parcels in a LIS is not unlike the survey plat. Although the bearing and distance masurements and other survey plat features are not shown on a typical map product, the land boundaries are the same. The basic capability to plot the lines remains the same for plat drafting as for LIS applications. One major difference, however, is that the map product may require a composite of several (or many) survey plats. This requirement is satisfied in an automated LIS by a data base which contains continuous, uniform cadastral parcel data.

As a part of BLM's automation efforts, the Public Land Survey System/Geographic Coordinate Data Base (PLSS/GCDB) is being developed. The PLSS/GCDB consists of geographic coordinates for corners, along with necessary attributes required to produce graphic displays and mapping products, using automated methods, to delineate the cadastral parcels. The PLSS/GCDB will provide the continuous, uniform cadastral parcel data.

The BLM has demonstrated the capability to link the PLSS geographic coordinates data with the land and mineral (ownership and use) records and natural resources data, and to use it in normal daily tasks which previously were done manually. The Farmington Demonstration Project in New Mexico showed the capability to use automated cadastral parcel data for oil and gas leasing activities. The Western Oregon Digital Data Base has further demonstrated this capability for timber inventory and management.

The format and content of the PLSS/GCDB is dependent on user requirements. These requirements include both the work functions which are to be performed, and the accuracy or quality of information which is needed. In defining these, requirements other than those of the BLM are being considered.

The PLSS/GCDB is being developed such that it may be useful to other Federal agencies, state and local governments. Data collection and management for local systems should be at a local level. However, the PLSS/GCDB will provide a standard base from which local governments may begin, and add special requirements to. This standard will ensure reasonable harmony of data where jurisdictional boundaries meet. It will also provide a vehicle for cooperative collection and exchange of data.

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THE EFFECTIVE USE OF COLOR IN CARTOGRAPHIC DISPLAYS

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ABSTRACT

The expanding availability of color for use with CRT and plotter displays is presenting greater flexibility in the design of cartographic output from geographic information systems. There now exists the potential to represent more information more effectively through the use of color. Both traditional cartographic displays and dynamic, spatio-temporal displays can benefit from the effective use of color.

It will be important, however, to use color in a manner that enhances the information content of the output rather than just randomly choosing colors for display. Many current displays combine colors in a way which is not easily interpreted by the reader. Logical combinations of color on traditional displays and logical sequences of color for dynamic displays need to be researched and described to achieve the maximum benefit from the current technology. Often, the color sequence that one generally thinks will be logical produces a display that is confusing and unreadable.

Prior experiments with simple dynamic displays and the evaluation of selected cartographic software packages have demonstrated that the selection of color combinations for a single display or the determination of an appropriate sequence of colors to represent temporal information are complex tasks. Successful transition from traditional cartography to automated cartography will be partially dependent upon developing known strategies for color selection to optimize the utility of the display.

1. INTRODUCTION

Improvements in the ability to display colors on CRT devices have been substantial in recent years and it can be anticipated that further improvements will be forthcoming. Early devices that could show only eight colors on a single image have now given way to devices having palettes of millions of colors. From such palettes,

a single image may contain hundreds or thousands of displayed colors. The capability of the display devices has progressed to the point where it is no longer sufficient to simply pick a few colors from a small set and expect to achieve the best possible result. Although the term "best possible result" is subject to individual interpretation in regards to color perception, the approach to color selection for CRT display images discussed in this paper should offer substantial advantages over non-systematic color selection techniques.

The objective of the color selection process can be stated as maximizing the information content of the image. In selecting the problem to illustrate the color selection concepts, the objective is to facilitate interpretation of the image without reference to, or need for, a legend. Thus, color should be used to convey more information regarding the display than providing a simple symbol. The relationship between the values of two or more mapping units should be shown by the color, not just that the units are the same or different.

Currently, color is used mainly to show differences which must be interpreted by reference to a legend. In some cases, gradations of color imply relative values (e.g., color bands on contour maps). However, some of these relationships may be "learned" by the user of the display in that the relationship has been established by common usage and is therefore expected. Other cases of color use appear to attempt to represent relationship (i.e., brighter is greater), however there is no evidence that color selection in these cases is systematic and reproducible, or that the reader of the display receives the desired image.

Examination of the use of color can be accomplished in one of two ways - derivation of general principles for selecting a sequence followed by testing in selected applications or by attempting to solve a specific case followed by generalization. As the interest of the authors of this paper is with spatio-temporal data and the various problems associated with handling and displaying such data, this has been chosen as a suitable problem for pursuing the color selection issue.

2. SPATIO-TEMPORAL DATA HANDLING

Geographic (or spatial) databases have already become so large that

effective data handling is a major concern. Interest is now growing rapidly for the development of spatio-temporal databases which will significantly expand the size and complexity of geographic databases. A full range of problems is expected in the development of such databases, from efficient and reliable input methods, suitable data structures, algorithms for problem solving, to effective means for display of the results. These results may be in the form of a simple query, where the user is examining some portion of the data base, or the result of a complex analysis or modeling process. Development of analytical, or modeling, procedures may also require a set of tools for examining the database to discover relationships between various subsets of the data. These databases are also likely to contain disaggregated data rather than summarized data, such as current databases like the U.S. Bureau of the Census' data. Thus, the demand placed on the geographic information systems will be compounded by at least three factors: 1) increasing geographic extent and greater detail through the use of disaggregated data; 2) the addition of the temporal dimension to the data; and 3) the desire to explore problems of greater complexity than is currently possible. Visualization, of the data, the solution process, and the result, will become an important tool for many researchers.

CRT displays, particularly ones capable of dealing with the anticipated complexity, are a major component of visualization. Advanced display techniques could be the spatio-temporal equivalent to interactive or exploratory data analysis in statistics (Hoaglin, Mosteller and Tukey, 1983; McNeil, 1977; Tukey, 1977; and Velleman and Hoaglin, 1981). Adopting the approach inherent in exploratory data analysis (EDA) is appropriate for large spatio-temporal data sets because the EDA approach emphasizes new ways of examining or "looking at" data. Although, some EDA techniques may be simple, they can effectively meet the objective of discovering patterns or relationships in the data which may not be evident when standard methods of spatial analysis are used. Particularly, correlation between spatial and temporal subsets of the data, not easily identified by traditional methods of analysis on the entire database, may become apparent through using the EDA approach. One of the four major components of EDA is data display. Velleman and Hoaglin (1981, xv) state "displays visually reveal the behavior of the data and the structure of the analysis." While they are referring mainly to the display of a spatial statistical data, the same, or even greater, importance can be placed on displays of spatio-temporal data. A significantly higher level of complexity is found in spatio-temporal databases. Spatial data presents additional complexity in that the locational component is two-dimensional and cannot be reduced to a single variable. Thus, the correlation with other variables (temporal or magnitude) is difficult unless the analyst already has some understanding of the

relationships existing in the database. With knowledge gained through the use of EDA-like tools, a large spatial database could be divided into spatio-temporal subsets suitable for further analysis. Understanding the nature and importance of interrelationships of spatio-temporal databases will facilitate the development of advanced GIS and spatial analysis.

A research effort toward the improvement of graphic displays of spatio-temporal data using some of the EDA principles is one way to address the problem. Improvement of graphic displays, in the context used here, is the use of color to a greater extent than has been done to date. Rather than simply using color to show nominal differences in the data, a systematic search for color sequences to represent ratio or interval data is advocated. Such a capability would provide an important element for spatial analysis, that of "flexibility, both in tailoring the analysis to the structure of the data and in responding to patterns that successive steps of analysis uncover" (Hoaglin, Mosteller and Tukey, 1983, 1).

An example of an important application area of spatial analysis which could benefit from improved displays is the study of traffic and goods movements in both urban and inter-urban settings (Schneider et. al., 1979). The need for improved computer graphics is described by Schacter (1983, ix) as: "Traffic systems are difficult to design due to the complexities of the many space-time interactions . . . The most detailed analysis are made by simulation. Through computer graphics, the simulation can be made visible, allowing the designers to better evaluate system performance. The objective of most current graphic simulations is to achieve realistic portrayal which reflects the condition of a network at some point in time. A continuous real-time graphic simulation, of course, would facilitate the understanding of system dynamics."

3. RESEARCH OBJECTIVES FOR EFFECTIVE COLOR USE

The objective of research in this area will be to discover ways to use color to achieve better understanding of large spatio-temporal databases and the results of analysis on such databases. The assumptions are: 1) that there will exist large spatio-temporal databases sufficiently complex to preclude effective apriori classification of the data; and 2) that visualization via the use of color computer graphics will be useful for understanding such data sets. The research tasks that evolve from this are the identification of systematic methods for selecting colors to

represent spatio-temporal data and the testing of these color patterns with both test data and real data to confirm that better understanding can be achieved. The remainder of this paper addresses the issue of selection of a set or sequence of colors to represent the temporal aspect of spatio-temporal data. This is, of course, not the only way in which color might be used to achieve the objective, but it is one approach which may prove feasible at the present time.

Currently, the display of data from geographic information systems, including the cartographic display of the results of analysis models, are deficient in two major ways. Current techniques of displaying the spatial and temporal components of data simultaneously (Clark, 1982) are not integrated and therefore do not permit the user to observe the space-time patterns of the data. The spatio and temporal components of the data are displayed in separate areas of the display device (Figure 1). Of greater importance is the fact that most cartographic displays are not interactive and therefore do not permit the user to examine spatio and/or temporal subsets of the data interactively to discover relevant patterns or relationships. Exceptions to the interactive problem are the simulations by Moellering (1980a) and Tobler (1975) which, through the use of animation, have some degree of interactive capability.

The need for improved cartographic displays has been noted by Moellering (1980a), who underscored the need to be able to "look at data" under user control. As geographic databases grow larger, the task of just "looking at the data" will become increasingly difficult. Clark's temporal displays (1982) succeeded in placing all the needed information on the display, but because of the separation of the spatio and temporal components of the display, space-time interactions are almost impossible to detect. Also, Clark's display of single point data (earthquake locations) is cumulative over time and as a large number of events appear on the CRT, the viewer loses track of the spatio-temporal relationships. Changing the approach to the representation of events to a structure where color is used to distinguish the temporal component of the data appears to have some promise.

4. ORDERED COLOR SEQUENCES

Initial efforts to introduce color to represent the time dimension of spatio-temporal data by Calkins (1984) showed limited success. A set of eight shades within one hue were achieved and it appeared that a viewer might perceive ordinal, ratio or interval data as a

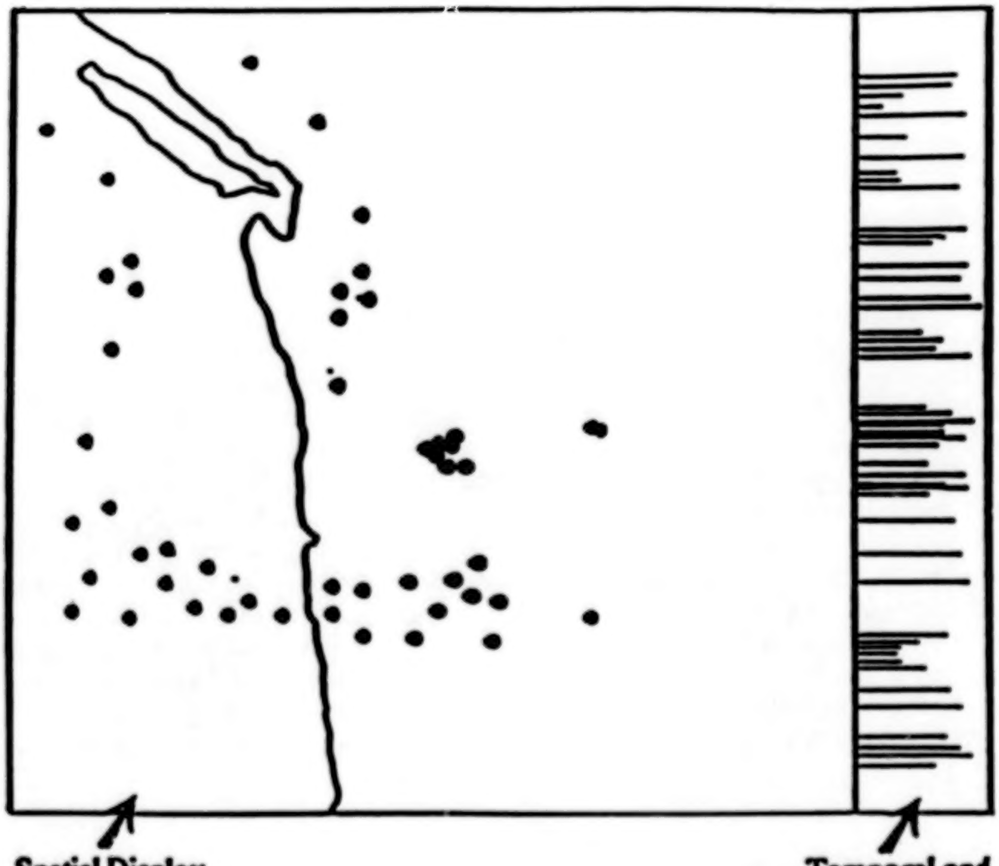

Figure 1. Space-Time Display of Earthquake Occurrence
Source: Clark, 1982 (reproduced by hand)

function of changing shades. This set of colors was not subjected to any structured testing as the technology in use at that time was clearly too limited to substantiate any claims. Use of a single hue seemed to achieve the desired result but there were not sufficient shades available on the display device to be meaningful. It was also noted that background color had a marked effect on the perceived shades. An approach using one color sequence as the background and another to represent the objects was also considered. Display device limitations again limited any experimentation with this approach.

More recently, Robertson and O'Callaghan (1986) have shown the feasibility of generating an expanded range of colors termed an ordered color sequence. This derives from advances in display technology and the use of uniform color spaces as the basis for selecting the color sequence. Robertson and O'Callaghan have described a method for defining a linear or non-linear vector through the HLS (hue, lightness and saturation) uniform color space to generate ordered color sequences which can be used to represent either univariate or bivariate data. The HLS color space is represented by a double hexcone (Figure 2). Any location within the hexcone, defined by values for hue (0 to 360 degrees), lightness (0 to 1) and saturation (0 to 1), specifies a unique color for display. Algorithms exist for taking the HLS values and calculating the equivalent RGB values for driving a CRT display device (Rogers, 1985).

5. USE OF ORDERED COLOR SEQUENCES FOR TEMPORAL DATA

A systematic examination of ordered color sequences to represent the temporal aspect of a given data set will necessitate definition and evaluation of many ordered color sequences. The range of experiments must allow for: 1) differences in color perception by different individuals, 2) different color preferences by different individuals and 3) different, and possibly varying background effects. For these reasons, the initial experiments are proposed on a simple data set - a set of observations represented by points only, such as the earthquake data used by Clark (1982). The information that needs to be known about each observation is: 1) the location of the observation or event; 2) one or more characteristics about the event, such as earthquake magnitude; and 3) the time of each event. The remaining description of the proposed research topic will cover only point type data events or observations. It is, however, recognized that a natural extension of representation of objects occurring at a single point in space will be the representation of objects moving through space over a defined time period. The ordered color sequences defined for point data should

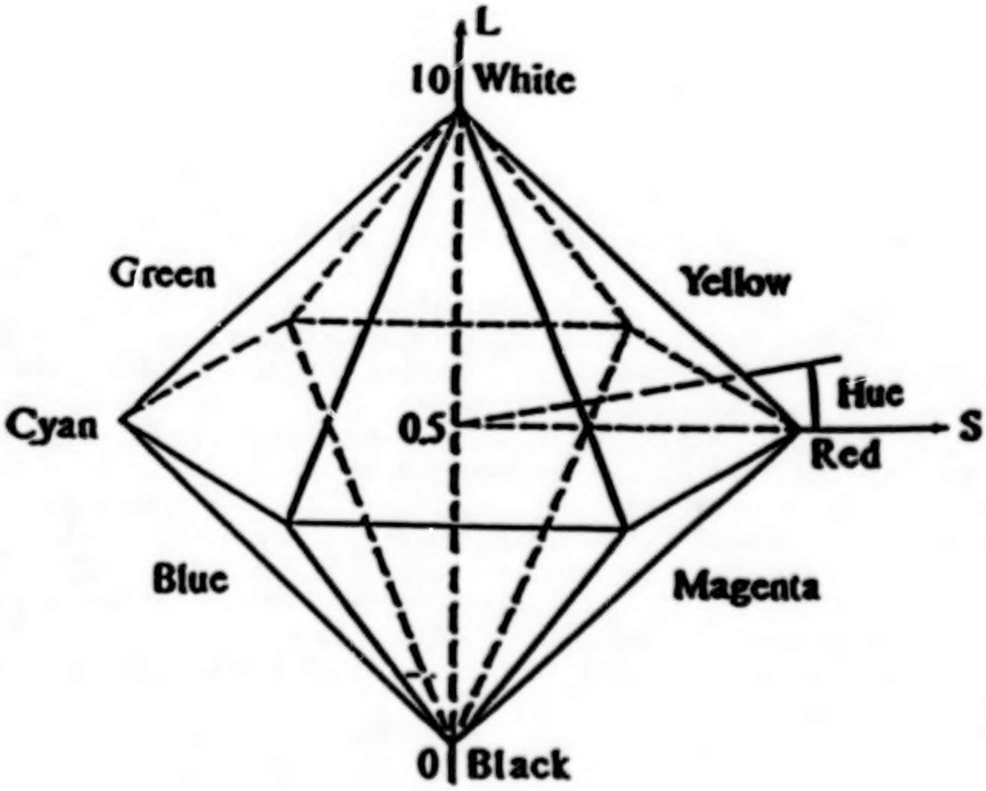

Figure 2. HLS double-hexcone color model.

[From Rogers, 1985 p. 404]

be equally useful in the display of other types of spatial data.

The proposed display technique for the earthquake data is to represent the earthquake epicenter by its X-Y coordinate location, the magnitude of the earthquake by the symbol size (graduated circles), and the time of earthquake occurrence by the color of the symbol. The objective of such a display is to facilitate the recognition of possible space-time patterns that in traditional displays may be obscured by preclassification of the data (i.e., a legend pre-defined for the time scale selects artificial boundary points).

The display of event times using ordered color sequences will be implemented in the following manner. The ordered sequence is denoted by: Color 1, Color 2, Color 3...Color N, (Color 1 and Color N being the extremes of the color sequence). Time is denoted by: Time T, Time T+1, Time T+2...Time T+N, (time increments under user control and time divided into N colors with time ranges under user control). As the first earthquake "occurs" (Earthquake 1 at Time (T)), a circle representing its magnitude, (relative to the magnitude of all earthquakes within the data set) will be plotted at the location of the earthquake, using Color 1. As the second earthquake "occurs" (Earthquake 2 at Time (T+1)), the circle representing Earthquake 1 will change from Color 1 to Color 2 and Earthquake 2 will be plotted on the display as a circle of Color 1. When the third earthquake "occurs" (Earthquake 3 at Time (T+2)), Earthquake 1 will be changed from Color 2 to Color 3, Earthquake 2 will be changed from Color 1 to Color 2, and Earthquake 3 will be plotted as a circle of Color 1. At this moment (Time T+2) the display will show the following:

Earthquake 1 (Time T) = Color 3
Earthquake 2 (Time T+1) = Color 2
Earthquake 3 (Time T+2) = Color 1

This sequence will progress as events continue to occur through time until Time (T+N). The resultant display, then, at any Time(T) will represent the most current event(s) in Color 1, recent event(s) in Colors 2 to N-1, and the earliest event(s) in Color N.

6. CONCLUSION

The use of ordered color sequences as proposed above may provide the ability to distinguish both space and time aspects of the data. It remains to be seen how users will perceive such a display and

whether or not significant spatio-temporal relationships, which would otherwise go undetected, can be identified. The use of earthquake data is the most elementary application of this display concept. If simple displays can be shown to be effective, and limitations from color display technology (including hard-copy techniques) are not over-restrictive, then other uses can be explored. It may be that significant results, or benefits, will be achieved through application of the display technique to more complex problems. However, first, it is necessary to fully understand the use of ordered color sequences before approaching the more complex problems.

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**THE QUEST FOR A FUNCTIONAL LIS:
A CASE STUDY OF PRINCE WILLIAM COUNTY**

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ABSTRACT

Prince William County, Virginia is one of the most rapidly growing jurisdictions within the Washington D.C. metropolitan area. The County has identified the need to acquire a functional Land Information System (LIS), based upon a multi-purpose cadastral concept, in order to effectively keep pace with the active development. A review of one local government's experience in designing a LIS reveals the need for: continuous administrative support, early coordination amongst users of the system, careful construction of a Request for Proposals (RFP), cautious consultant selection measures, and constant monitoring of the various tasks associated with such an endeavor.

1. INTRODUCTION

Prince William County is located in Northern Virginia, approximately 35 miles southwest of Washington, D.C. . With an estimated population of 203,500 and a land area of about 350 square miles, Prince William is the third most populous County in the Commonwealth of Virginia. Prince William is one of the most rapidly growing jurisdictions in the State; there has been an estimated 41% change in population from 1980 to 1987. Current projections anticipate a population of 240,000 in 1990 and 317,000 by the year 2000. Currently, the County has some 70,000 parcels of land, and based on trends in 1985 and 1986, expects over 6,500 new parcels to be created through subdivision each year.

Prince William County is governed by a seven member elected Board of County Supervisors and operates under the administration of an appointed County Executive.
Of the 34 different county agencies, there are 15 agencies

directly associated with the land use information.

Recognizing the importance of land related information, Prince William County has made this an area of emphasis for the past four years. In 1983 a Land Use Information Committee was created by the County Executive. This committee seeks to improve the coordination and information sharing among the various agencies that collect and disseminate land related information. The committee is comprised of department heads from fifteen agencies and is chaired by the County Executive. Further, this steering committee serves as a coordinating body for resolution of land information issues and recommends policies to the County Executive necessary to improve processes and promote effective management of land information.

The steering committee established a subcommittee which deals with the technical issues related to land information. The Land Use Information Technical Committee is comprised of persons with technical knowledge of the use and management of land information in their respective agencies. This group makes recommendations to the steering committee on policy and procedural issues.

Both the steering and technical committees recognized the need to evaluate the County's existing land information systems and recommend ways to increase the efficiency of government operations. Thus, an assessment of current systems was conducted and various deficiencies were identified. In order to correct such problems, the technical committee considered upgrading the existing system or conceptualizing a new automated land information system. The technical committee recommended that the latter option was in the best interest of the County. However, due to the staff's lack of expertise and experience in developing such a system, the technical committee recommended that outside assistance be secured. Once the steering committee and then the Board of County Supervisors agreed with this strategy, the technical committee produced a Request For Proposals (RFP). The purpose of this RFP was acquire a "conceptual design" of a desired system. Once a conceptual design was agreed upon, a technical design would be developed (through a second RFP) which would recommend the necessary software and hardware to operate the County's envisioned LIS.

2. LAND INFORMATION SYSTEMS IN PRINCE WILLIAM COUNTY

The County has a number of automated and manual information/application systems that perform limited functions quite well. There are seven major automated systems that form the basis for the current Land Information System. The majority of these systems maintain real estate assessment, tax bill, building activity and voter registration information. There are also numerous manual systems which either support or supplement the automated systems. These first and second generation application systems were designed to meet specific requirements with little in the way of global models, plans or standards that might allow information sharing or linkages between systems. Because of the rapid growth of the government and the population it serves, Prince William County's application systems have struggled to keep pace with increasing demands and expanding requirements.

Twenty-two application systems which run on the County's two Hewlett-Packard 3000/Series 68 minicomputers. One of the minicomputers is devoted exclusively to public safety functions and the other serves all other functions. Recently, the County has acquired a turn-key automated mapping and geographic information system (GIS). The Prime minicomputer which supports this application is located within the Mapping Office. The automated mapping and GIS will be the basis for the LIS applications that require spatial processing and manipulation of information. Therefore, it is critical that it interface with the overall system.

Two computer systems outside the general county government also have need for interfaces with the Land Information System. The Prince William County Public School Board and the Clerk of the Circuit Court require access to data and extraction of data for update and analysis of files.

3. IDENTIFIED PROBLEMS OF EXISTING LAND INFORMATION SYSTEMS

The assessment of the existing systems identified a number of problems which have impeded the County's goal of securing a conceptually unified and technically sound land information system. Since 1983, County agencies have been actively engaged in identifying and addressing the

following general problems.

3.1 Lack of Unifying Concept or Model

While nearly all agencies associated with the County government have an involvement with land information, their perspectives, requirements and interests differ. The situation is complicated further by the diverse regulatory requirements and organizational relationships that determine how agencies must operate. Achieving a system which will enable information sharing between agencies is a formidable task. The County has lacked a model or concept which allows geographic information and attribute data to be layered and linked in a flexible manner. Indeed, most systems have been developed independently with little thought to information sharing and linkages.

3.2 Lack of a Unique Parcel and Structure Identifier and Cross Index

Each agency has some method of uniquely identifying and accessing the land information it maintains; these identifiers vary by agency and account number, permit number, mapsheet, deed book and page number, owner's name, etc.. The County lacks a reliable mechanism to enable sharing, updating and cross indexing of the information maintained by the various agencies. Most often, relating one set of information or files to another is cumbersome and requires human intervention and decision-making to ensure that the information pertains to the same unit in order to extract the needed data. In many instances, this deficiency has led to situations where several agencies are maintaining the same data and are not communicating or updating it effectively.

When addressing the issue of a unique identifier, some confusion emanates from the need to distinguish not only between individual parcels, but the various units or structures built upon them. The premise address is an imperfect tool for this purpose because it may not be absolutely unique (due to addressing problems, subdivisions, etc.). Also, it may change over time, does not consistently differentiate among structures or units at the site, and does not lend itself directly to geoprocessing.

The real estate account number has been used more than any other key as a parcel identifier, but overall, it is ill-suited to this correspondence with either the parcel or the units. It also may change over time due to change in ownership and may not adequately reflect changes in the parcel definition. Substantive time lags in updating ownership and subdivision data during six months of the year, diminish the usefulness of this information source.

In summary of this item, the County lacks a satisfactory geographically based identifier for parcels that can be used both to link related information and allow aggregation or geoprocessing of information.

3.3 Information Updating and Hierarchy

County agencies need to share updated information routinely. This does not occur satisfactorily for several reasons. The foremost problem is that data relationships have not been adequately defined, nor does any plan exist to ensure reliable and expedient updating of information across all systems. In other words, systems contain some data for which no sound method of updating has been established, seriously undermining data quality. Further, there are redundancies and inconsistencies among data in automated systems. Even where updated information is transmitted between systems, it generally requires a rather painful human interface to update records maintained by the various agencies. The manual nature of many operations (notably the mapping function) makes updating difficult and seriously delays communication of changes. Even between automated systems, the updating process is not generally efficient or reliable.

3.4 Data Quality

Data quality problems occur in a number of instances. One major problem is the propagation of data that is inconsistent between systems. Currently, new records are not edited against a standardized listing or data source to ensure their accuracy and consistency with data on record. Thus, for the same piece of property, records of the various agencies may have inconsistent addressing, spellings or other information discrepancies. Other data quality problems occur as a result of procedural

deficiencies in the day-to-day operation of systems. Some other problems occur because of the current lack of any reliable and efficient methods to cross check, update and correct records.

3.5 History Files/Retention of Information

The County lacks a standardized approach and reliable method for chaining history on parcel changes and administrative actions affecting a given property. Retention schedules need to be developed for all data elements, indicating to what extent history must be maintained and the standards, limits, and responsibilities for retention. For example, chain of title is maintained to some extent in the Assessments system and in manual files in the Office of Mapping. It is stored (though not conveniently accessible) in the files and in the new automated indexing system of the Clerk of the Court. Tracking administrative actions or records affecting properties is problematic with the existing systems. It is difficult to track the relevant permit numbers, plan numbers and case numbers affecting a particular piece of property, and nearly impossible when the property is subdivided or altered. The County needs to establish requirements for history and develop capabilities to maintain and retrieve historical data.

3.6 Deficiencies in Systems Development Methods and Tools

Systems developed by staff or consultants had few standards regulating structure and documentation. The automated assessments system, which was developed in the late 1970s by a consultant, is a noteworthy example of this problem. While the system has many functional components, these are not adequately segregated and documented. Thus, when a change must be made to a particular component, it is difficult to identify which lines of code must be changed to accomplish the modification throughout the system and to identify where and how the modification would affect other components.

In many cases, databases are partially tied to the applications programs which use them, so that changes in the data structures require either changes in the applications programs or changes in the data dictionary.

With the passive database management system currently in use, maintenance/modification of applications is more labor intensive. It is abundantly clear that the future of land information systems in Prince William County entails considerable growth and change. The overall design of the next generation system must allow flexibility and facilitate change. Standards and protocols are needed to enable linkages.

3.7 Need for Numerous Additional Capabilities

All of the land related automated systems currently in use need enhancements and added capabilities. Again, most were designed to accomplish rather narrow functions. Often the systems automate only limited aspects of a process, with manual processes and microcomputer application bridging the gaps with varying degrees of success.

The listing of processes that should be automated is sizeable, and enhancements and modifications have been postponed in several instances until the LIS technical design is complete.

3.8 Mapping System Deficiencies

The importance of the mapping function has come to the forefront through the County's efforts to develop a conceptually unified information system. The mapping function evolved rather independently of the automated application systems; only in the last several years has serious thought been given to attempting to link the land information reflected in the County's maps with the related data stored in the automated application systems. The existing mapping system must change materially in order to meet the information requirements of county agencies and allow geographic information to be shared efficiently and effectively.

The County has taken a number of positive steps to upgrade the mapping function. This function has been elevated to its own Office, rather than a subsidiary of another unit. Staff has been added and additional resources have been committed. Of primary importance is correcting the

positional accuracy of mapped data; this is essential if "layers" of information are to be shared and linked to a single parcel or location of interest. Additionally, automation is essential to bring the mapping function to the point where information can be updated, stored, accessed, manipulated and retrieved with ease. Plans for improving the positional accuracy of mapped data and for automating mapping functions are, at present, being implemented.

4. GENERAL REQUIREMENTS FOR THE ENVISIONED LIS

The County's general requirements that the unified LIS should meet are:

- adherence to the multi-purpose cadastre concept,
- reliance on a parcel master database and index,
- reliance on a unique parcel identifier,
- incorporation of information management and data quality standards,
- incorporation of audit and security standards,
- basic adherence to current organizational functions and relationships,
- interface with the automated mapping and GIS component and,
- ability to add enhancements and additional capabilities.

4.1 The Multi-Purpose Cadastre Concept

The concept of a multi-purpose cadastre arises from work of the National Academy of Science to establish a common conceptual framework for land data for scientists and practitioners in the field. A cadastre is a collection of records that relate to property ownership rights. The parcel (generally, the smallest unit of ownership) is used as a key for accessing and relating all types of land information, of which ownership is one element. This framework is being adopted by many counties across the nation. To be applied effectively, the following

requirements must be met:

- a geodetic control network must be in place, to enable accurate establishment of spatial coordinates.

- an accurate large scale base map that provides key geographic features which are tied to the geodetic control network.

- a series of overlays of the various features of interest must be created (e.g., streets, zoning, soils, watersheds, flood plains, service areas, etc.). Of primary importance is an overlay that depicts parcels.

- a series of files may be related to the map overlays containing selected attributes of the parcels, streets, etc., that are included as overlays.

- a linkage mechanism is required for relating geographic identifiers in the files to geographic points, segments and areas.

4.2 The Parcel Master Index and Database

At the core of the proposed LIS, there must be a central "corporate database." This database must contain accurate and up to date information that is routinely relied upon by applications programs as well as general system users. The parcel master database must be available to serve information needs for all users.

The system must provide an indexing capability or table of equivalencies in order to relate the identifiers used by the various agencies for their administrative purposes. The objective is to enable a crosswalk between files.

The parcel master database should serve as a basis for and a check against any new record created. Currently, a major problem is the propagation of inconsistent data in the existing systems. The parcel master should contain data for every bona fide parcel in the County and it should be updated with great expediency to reflect any changes in ownership, description, etc..

Consideration should also be given to the need for a related file for structures. Many agencies have an interest and collect information related to the structures or units built on parcels. This is a particular consideration in shopping centers, condominiums and apartments. Thus, while the parcel is the unit of most common interest, it is not the "lowest common denominator."

4.3 Unique Parcel Identifier

The County requires a unique parcel identifier with a geographic basis to enable geoprocessing of parcel related information. Generally, the coordinate value of the parcel centroid is used for this purpose. However, some provision must be made for condominiums, apartments shopping centers, etc., to further distinguish units.

4.4 Information Management and Data Quality Concepts

Information is a resource that must be managed similarly to any other. A life cycle perspective must be taken on questions of information management. A plan must be in place for the creation, maintenance, updating, storage, retrieval and disposition of information. Insufficient attention has been devoted to information management in most of the land information systems currently in use by the County. Every data element must have a plan for its creation and updating. Data flows must be defined and appropriate mechanisms for updating information throughout the County must be established.

4.5 Audit and Security

Complementing the County's concern with data quality, is an emphasis on audit and security requirements. This would include a disaster recovery plan that will enable continuation of vital operations dependent upon the automated system in the event of loss of automated capabilities.

4.6 Basic adherence to Current Organizational Functions and Relationships

The County has an interest in improving the flow of land information to the fullest extent feasible. Some changes so far as sequencing of routing or data entry may be readily made. There is less flexibility so far as changing the functions or organization of agencies. Though recommendations would be entertained from the contractor, this is not an objective of the design project.

4.7 Interface With the Automated Mapping and Geographic Information System Component

Prince William County has taken several important steps toward automation of the mapping function and establishment of a sound geographic base for the LIS. The County has approved of: establishment of a geodetic control program, completion of the recompilation of the parcel overlay, development of an updated photogrammetrically derived base map in digital form for approximately one third of the County, acquisition of an automated capability for street-networking maintenance, and acquisition of an automated mapping and geographic information system.

Improvement to the County's geodetic control network through establishment of a geodetic control program is fundamental to improved data quality. The geodetic control network of monumentation provides accurate reference points for State Plan Coordinates that can be used by all surveyors and cartographers. The County plans to add approximately 50 second order monuments and will add a professional surveyor to the staff to administer the monumentation program and provide professional review capabilities on survey data quality issues. An ongoing program will enable the continuing densification of the control network through both public and private monumentation efforts.

In addition to these identified requirements, the system is envisioned to accommodate further enhancements and capabilities beyond the core capabilities.

The core capabilities form the foundation of the larger system. Capabilities considered core are:

- a Parcel Master database and DBMS that are capable of supporting the full system requirements,
- interface with the automated mapping and geographic information, and
- productivity tools for systems development and user information management.

The functional LIS will allow all existing land information applications to use the DBMS and relate in some fashion to the Parcel Master database at some point in the future.

5. PROGRESS OF THE QUEST

Prince William County has made considerable progress in its quest for a functional LIS. With the support of the elected officials and the County Executive, significant accomplishments have taken place. For example, once a Conceptual Design was completed in 1986, work began on the technical design.

5.1 The Technical Design

The process for acquiring a technical design for the new system was similar to that of the conceptual design. That is, with support from the Board of Supervisors and guidance from the steering committee, the Land Use Information Technical Committee developed an RFP and then selected the appropriate consultant. (There were actually two separate releases of the RFP as the first release did not attract a satisfactory response from those bidding on the project.) The contract on the technical design was awarded in the Spring of 1987 and since that time, the following major tasks have been completed:

- current functional requirements,
- DBMS/hardware specifications,
- design alternatives,

- major design specifications, and
- interface controls.

Those tasks which are currently in progress include:

- detailed design specifications,
- a LIS logical data base design, and
- an implementation/transition plan.

5.2 Unexpected Issues

Throughout "the quest," several unexpected issues arose. For example, the task of creating a unique parcel identifier became a debated point because certain agencies were satisfied with a "parcel centroid" i.d., while others (Fire Rescue Service in particular) were concerned with the individual structures or buildings existing within the parcel. Thus, in addition to a parcel i.d., a structure i.d. was also created.

Another issue that required more effort than had been anticipated, relates to the question of data ownership and data maintenance. Of the 489 data elements to be included in the new system, 55 of them could not find "owners" which meant that "data workshops" were implemented in order that such information would be revealed and eventually it was.

Still other unexpected issues prevailed which dealt with: interfacing with the newly acquired GIS; reconciliation of land use codes; interfacing with the utility companies; multiple ownership of a parcel, etc. . The issues or problems have not all been solved. It seems that in the process of resolution, additional questions continue to be generated. The result of this has been an increase in the exchange of information from one agency to another and, concomitantly, a heightened awareness of "what everybody else does" who works for the County.

6. CONCLUSION

The quest for a functional LIS in Prince William County continues and the lessons to be learned from this experience are plentiful. Local governments which recognize the need to improve upon its operations in order to better serve its citizens, can look to this new technology for solutions. However, without a strong commitment from all levels of the organization, it is difficult to imagine how such an endeavors can be successful.

Today's LIS/GIS consultants and their local government clients continue to be pioneers within the areas of data base management, applications development, and creation of automated mapping functions. Further research and implementation of these systems will achieve the principal goal of providing a better government for the citizenry.

Costs and Benefits of GIS: Problems of Comparison

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1. INTRODUCTION

Numerous experiments, pilot projects, and full scale efforts aimed at implementation of geographic information system (GIS) technology have been carried out over the last ten years. Some of these activities have focussed on one-time needs such as facility siting, political redistricting, or identifying certain soil characteristics; others have been directed toward longer term and routine needs such as tax assessment, watershed management, or emergency preparedness. Within the community of developers, managers, and users of GIS, it is often assumed but seldom documented that a GIS approach can do the job better: it costs less for a comparable or better result than can be achieved through traditional methods.

In many cases, it has been difficult to quantify savings with traditional benefit cost analysis techniques. The GIS model being implemented varies from place to place, so costs may not be directly comparable in similar but not identical situations. And baseline information on the costs of managing geographic information by traditional methods is especially scant, making cost comparisons difficult to place in an appropriate context. The recognition and measurement of benefits arising from a GIS is even more problematic, since benefits may be indirect in addition to direct, and may not appear until some time in the future. In particular, the value of activities that could not or would not be attempted with manual techniques is hard to assess. Also, long term benefits of multipurpose systems will accrue when data does not have to be collected anew for as yet unanticipated non-routine applications. Yet most implemented systems have insufficiently long histories for the true costs of continuing database maintenance to have been demonstrated.

A group of studies in Wisconsin provides a basis for viewing costs and benefits involved in a GIS approach to spatial information management. First, the costs of carrying out routine land records management by traditional means will be described; a 1976 study compiled the cost of all local and state mapping activities in Wisconsin. Second, expenditures for a pilot project multipurpose cadastre in one township will be examined, in comparison with costs based on an estimate model produced by a panel for the National Research Council; the documented costs include those needed to create

an automated system that meets all local land records needs. Third, the cost and the resulting database for soil erosion control planning by manual and automated methods will be compared; these costs are based on a multipurpose land information system project in Dane County.

The implications of these economic considerations of GIS create a set of issues which should be placed on the research agenda along with the many other aspects of this emerging technology which are being identified. Particularly with the large investments being documented for computing in general by various levels of government, the economic factors related to GIS implementation and operation should be explored and better understood.

2. BENEFIT COST ANALYSIS FOR GIS IMPLEMENTATIONS

As a substitute for traditional market forces, benefit cost analysis can be used to guide decisions or evaluate performance. By attempting to recognize and evaluate all of the benefits and costs of various alternatives, the structured approach of a benefit cost analysis imposes order on the decision making process. Use of this technique may be critical in the public sector, and especially so in times of fiscal restraint, as well as in times of relatively rapid transition into automated technologies (Wisconsin Land Records Commitee, 1986).

3. COSTS—THE FOCUS OF ATTENTION

Cost studies are an important element in understanding some of the broader context of GIS. The component costs for management of geo-referenced information can be divided by various schemes. Some basic categories can be data collection, interpretation, and structuring, maintenance, storage, dissemination, and formatting, and analysis and communication of information. Costs associated with many of these categories can be measured, estimated, sampled, or assembled in a relatively direct manner. In public agencies particularly, budget conciousness alone may explain the predominant focus in the literature on costs, as compared to benefits. Reinforcing this tendency is the fact that recognition and assessment of benefits may be much more problematic than studies of costs. Nevertheless, valuable insights can be derived from cost studies alone.

3.1 The Cost of Routine Land Records

A 1976 study (Larsen et al, 1978) estimated annual expenditures for land records in Wisconsin. In addition to being the only study of its kind to date, the Larsen report is also useful because Wisconsin as a state is average in population and area among the 50 states. Expenditures for 1976 were sampled from local, state, and federal governments, plus public utilities; by extrapolation a statewide cost of $80 million was derived. This sum translates into $17 per capita ($34 per income tax payer) or $2.25 per acre statewide. Not included were private costs such as title searches, title insurance, and property surveys. Over half of the measured expenditures were found to be at the local level of government.

The 1986 figures become $117 million, $25 per capita, and $3.30 per acre, after updating for inflation over the intervening decade, a logical assumption since these routine types of costs continue year after year unless dramatic shifts in mandates, user demands, or technology implementation occur. Therefore, approximately $1 billion can be estimated as having been expended from 1976-1986 for routine land records collection and maintenance in Wisconsin. The persistence of these annual expenses implies that society, through its institutional structures, perceives that benefits are being derived which at least equal the costs incurred. Viewed more wholistically however, there is evidence that implementation of multipurpose land information systems could effect savings over traditional methods. This is because individual agency managers of land information typically have understandably restricted (and different) perceptions of the need to collect, maintain, cross reference, and disseminate the particular information that they are charged with managing (Portner and Niemann, 1984). In this context the managers might not perceive potentials for information sharing or systems integration that could reduce overall costs.

The relatively high level of expenditures revealed in the Larsen study means that the considerable resources needed to implement a GIS approach should be available if the appropriate officials become convinced that benefits at least comparable to those produced by traditional methods can be expected, and if the necessary modulations of institutional relationships can be effected without raising excessive resistance.

3.2 Projected Costs

In 1983, the National Research Council developed estimates of the costs that counties could expect to incur if they proceeded to develop multipurpose cadastres (NRC, 1983). (Here, a multipurpose cadastre means a property parcel based information system, not necessarily automated; it could be a type of GIS under certain conditions). Cost estimates were developed for two prototype counties, one rural and one urban. (The major differences between these two types of counties were in population and parcel densities). The NRC study was based on a multipurpose system model beginning with a base map layer and including a reference framework and cadastral layer.

The NRC prototype estimates assumed that measured coordinates of Public Land Survey System (PLSS) corners, or comparable metes and bounds reference points would be included, in addition to the national geodetic reference system. This assumption is logical, given the small incremental cost to add the coordinates of these points to the system. This approach is even more applicable in 1987 than it was in 1983, with the much wider use of Global Positioning System (GPS) technology for these purposes. Other technologies such as aero-triangulation can produce similar cost efficiencies under the right conditions. Based on 1983 technology, the NRC estimated the reference framework would cost $2.3 million in an average size county. Estimated costs were the same for both urban and rural prototypes since the density of monuments needed is the same for both areas (See Table 1).

Table 1
Per County Multipurpose Cadastre Component Cost Estimates

Item	NRC Prototypes: Urban	Rural	Dane County, Wisconsin
Population (000)	500	200	331
Area (sq.mi.)	956	956	1200
Parcels (000)	200	15	135
Reference Framework ($000) (Relocation and Coordinates)	2280	2280	2880
Base Maps ($000)	1480	796	1854
Cadastral Layer ($000)	2000	150	1350
To'al County Cost ($000)	5760	3226	6084

Source: National Research Council, 1983, pp. 116 & 118, and Wunderlich and Moyer, 1984, p. 194.

Base maps were assumed to be produced by traditional methods. Here costs varied widely between the prototypes, depending on population density and parcel density. The range in costs was between $800,000 and $1.5 million.

Cadastral layer costs ranged even more widely for the prototype counties, from $150,000 to $2.0 million. The variation in this layer was directly related to the number of parcels in each county, with a cost of $10 per parcel assumed. The cadastral layer was expected to include several types of information.

The NRC overall cost estimates for development of a county level multipurpose cadastre were $3.2 million for the rural prototype and $5.8 million for the urban prototype.

3.3 Applying the NRC Estimated Cost Model

Wunderlich and Moyer (1984) used the NRC model to estimate land information system (LIS) costs for Dane County, Wisconsin. (Here, the term LIS is considered to be a subtype of the more general category of GIS). They concluded that such costs would be slightly over $6.0 million. However, they noted a number of factors that would reduce the actual costs incurred by governments in many situations. For instance, they noted that many counties already have some or most of the land information systems components in place. That is, base maps may be already completed, at least part of the cadastral layer may be in place, and some of the

reference monuments set and coordinates determined for them. Therefore, Wunderlich and Moyer concluded that the NRC estimates should be considered as maximums.

Wunderlich and Moyer also suggested that there is potential for cost reduction due to the availability of new technology. These technologies seemed affordable, given the large sums of money that were being expended on an annual basis for current single purpose, uncoordinated systems (See Larsen, above).

In spite of the work of the NRC and others to develop coherent methods for estimating multipurpose land information system costs, there is still much work to be done before any "standardized" estimating procedure becomes widely accepted. This lack of acceptance is due to the relatively recent development of multipurpose systems and concepts, the complexity of these systems, the need for foresight in systems design when assembling and linking components that have long been treated as standing alone, and the fact that the various mandates administered by agencies create different needs. In addition, there is often a lack of adequate information on the current status of system components (i.e., how much is already in place, and the interrelationships existing—whether by design or not—amongst these components), and which of several approaches is most appropriate to use in developing the system in a particular county.

3.4 Costs of a Single Township Multipurpose Cadastre Pilot Project

Some of the factors which tend to obscure cost estimations and comparisons become apparent when comparing the NRC results discussed earlier, with the estimates for the Township of Randall pilot project in Kenosha County, Wisconsin (SEWRPC, 1985).

The major finding of the Town of Randall study was "...that the implementation of a limited purpose automated mapping and land information system...is feasible with existing technology, and that development of such a systems can be accomplished—at least in Kenosha County—at a reasonable cost". Cost estimates for the township were made on a per square mile basis (See Table 2, below). The combined cost for the system as configured for the project was $8163 per square mile. This compares with the urban estimate by the NRC of $6025 per square mile, and $5070 per square mile estimated by Wunderlich and Moyer for Dane County, Wisconsin. Much of the variation between these estimated costs is due to assumptions made about the LIS being developed. For instance, the Town of Randall system included PLSS quarter section corners when estimating relocation and coordination costs for the reference system, while the NRC systems included only section corners. Also, the Randall costs include building digital map files for a number of "layers" of data that were not included in the other prototypes. These differences point out the need for caution in using cost estimates developed by others. Details on specific system components are critical, as are details on how these components will be built and maintained.

Table 2
Per Square Mile Cost Comparisons of Multipurpose Cadastre Component Costs

Item	NRC Prototypes Urban	NRC Prototypes Rural	Dane County, Wisconsin	Town of Randall, Wisconsin
Reference Framework Relocation & Coordination ($)	2385	2385	2400	1400 2200
Base Maps ($)	1548	832	1545	1960
Cadastral Maps ($)	2092	157	1125	1200
Digital Files ($)	-NA-	-NA-	-NA-	1404
Total ($)	6025	3374	5070	8164

Source: Table 1, and SEWRPC, 1985, p. 59.

3.5 Cost Implications for LIS from studies of Developing Countries

Bernstein, in recent work for the World Bank (Bernstein, 1987), notes that accuracy level required, quantity of existing information available, and local conditions all vary from place to place. She suggests that it is therefore risky to generalize cost experiences or projections from one country to another. Between countries, different social systems and conditions will give rise to different sets of user demands for information and different values (e.g., different expectations about data accuracy, currency, availability, and compabitility) associated with the needed information. (Bernstein also notes that more consideration needs to be given to determining the appropriate parameters for which unit costs are sought when developing comparisons between systems). We believe that these considerations can be applicable to inter-city, inter-county and inter-state comparisons as well.

4. BENEFITS: NOT WELL DOCUMENTED, RECOGNIZED, OR MEASURED

While we have noted a number of problems that relate to accurately determining costs of developing and maintaining multipurpose land information systems, these problems pale in comparison with the difficulties in dealing with the benefits on the other side of the benefit/cost equation. These difficulties relate in part to the complexity of benefit/cost analyses in general. For instance, benefit cost analysis "usually identifies a larger number of effects that should be considered...". (Epstein and Duchesneau, 1984). Furthermore, benefits (as well as costs) can be categorized in a number of ways, for example direct and indirect (i.e., linked with the project, not part of it per se), and as quantifiable and unquantifiable (due to lack of data to use in the evaluation, or due to the fact that the factor being evaluated is of an intangible nature).

Some benefits are easily approached for analysis, such as a reduction in time for accessing a particular public record, or reduction in time or expense in linking spatially related information from different sources. But the ultimate benefits of such improvements can be elusive to track and document, much less measure. For example, wetlands regulations may be more uniformly enforced; an appropriate site for a new manufacturing facility may be located in one state before competing states can perform similar analyses; proximity of sources of toxic pollutants may be linked to contaminated ground water. There are, in fact, multiple levels of benefits, corresponding to the values perceived by various sectors of society. Subsets of these levels of general benefits are likely to be found dispersed amongst various groups at different levels in bureaucracies, businesses, public interest organizations, as well as to individuals.While all of these factors make the economic evaluation of land information systems difficult, they should not be considered fatal to the evaluation process. As Wallin noted, one procedure is to explicitly include all benefits (and costs) even if it is not possible to quantify all of them. (Wallin, 1985) In this manner, decision-makers will still have the opportunity to take the non-quantifiable effects into account as they evaluate a project or system.

There are a number of ways to combine benefit and cost data into an analysis. For example, the Wisconsin Land Records Committee (WLRC) Subcommittee on Benefits and Costs suggested several ways, ranging from a simple checklist to a complex mathematical evaluation (WLRC Subcommittee Report #2, June, 1986). The preferred approach (i.e., level of complexity) depends on the particular system being evaluated or decision being made. Generally the larger the impact of the decision (i.e., in terms of costs and benefits), the more effort needed to ensure a complete, fair evaluation.

The recognition that evaluation of land information systems is difficult is not a recent one. In fact, a number of the problems of such an analysis were identified by Hans Larson in a ground-breaking study in 1971 (Larson, 1971). He noted he was embarking on "what should become an on-going monitoring and evaluation process..." (p.ii) Larson also noted that what was needed is a new body of knowledge on "The Economics of Surveying, Mapping and Land Property Information and Control Systems". (p.ii) Such a body of knowledge and evaluations based on it require:

"1. a full understanding of all the processes under study, and
2. adequate qualitative information on all essential facets of these processes" (p.ii)

Larson noted major shortcomings in this regard in his study. We believe these shortcomings are still largely true today.

However, progress has been made in a number of areas. Epstein and Duchesneau (1984) applied benefit/cost techniques to the question of the economic value of a geodetic reference system. Specifically, they argued that substantial benefits accrue to land information users who need "accurate compatible, spatial information for decision making." (p.v) These users "need to combine or integrate information and data originally produced for narrow-based primary purposes". (p. v) They conclude that the major portion of benefits accrue from use of "spatial information based on a

geodetic system by secondary and tertiary users". (p. v) Use by these non-primary users, coupled with the fact that benefits will occur in a stream over a long period of time, also contribute to the difficulty in valuing benefits of LIS. (For example, the value of the benefits in this time stream need to be converted to a "present value" basis, in order to compare benefits with costs, which typically are "loaded" near the beginning of a project or system development.)

Epstein and Duchesneau conclude that information compatibility, resulting from the geodetic reference system, helps non-primary users avoid costs they would otherwise incur in combining and integrating data. They then equate these avoided costs to benefits.

Some work by Blaine and Randall (1987), suggests that the cost avoidance model, while valid to a point, may in many cases underestimate the benefits that a modern LIS will produce. They argue that, by easing access to data and analytical techniques through the use of a georeferencing system, demand for the products of the LIS will increase. The increased demand will tend to reduce costs, such reduction in fact producing further benefits. Blaine and Randall acknowledge that the remaining task for the LIS community is to develop specific estimates of these potential benefits. These benefit estimates will in turn depend on the identification of demand and marginal costs for both traditional and new uses of the LIS. This expanded model may be applicable to geographic information in general, but to our knowledge empirical examples have not appeared in the literature.

5. WHAT IS NEEDED: DETAILED ANALYSES OF SPECIFIC APPLICATIONS, BASED ON COSTS OF MANUAL VERSUS AUTOMATED METHODS

Based on work discussed in the previous sections, and the LIS development and analysis work carried out at the University of Wisconsin—Madison over the past 18 years, we have reached a number of conclusions concerning what is needed to produce the economic evaluations needed by decision-makers who must fund, develop, and maintain the LIS of the future.

5.1 Costs For Soil Erosion Control Planning

Over the last few years, Wisconsin counties have been in the process of developing soil erosion control plans to comply with state legislative mandates. The methods used to construct these plans have varied widely, based on broad guidelines (Wisconsin Administrative Rules, 1984) promulgated by the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP). The costs of plan preparation have been shared by the counties and DATCP.

As a product of prior research and pilot projects, a GIS approach to soil erosion control planning was utilized in Dane County (Ventura et al, 1987). Computer models were constructed to analyze data and develop the graphic and tabular results needed for

the plan. Cost estimates were developed for data acquisition and interpretation, map and attribute digitizing, database assembly, model development, analytical processing, and output production. Projecting these costs across all counties affected, DATCP would have invested no more in compatible statewide digital plan production than it did in other diverse methods, had GIS technology been readily available (see Table 3).

Table 3
Costs to produce automated data layers for soil erosion control planning in Dane County, Wisconsin

Layer	Cost[1]		
	Per Square Mile	Per Township	Statewide[2]
Soils[3]	12.00	432.00	480,000
Land Cover[4]	1.50	54.00	60,000
Wetlands[5]	.05	1.80	2,000
PLSS[6]	3.75	135.00	150,000
Production[7]	3.00	108.00	120,000
	$20.30	$730.80	$812,000

1 Based on personnel charges of $12.00 per hour, computing costs of $1.50 per CPU minute and $1.00 per connect hour on VAX 8600 computer.

2 Extrapolated costs for the approximately 40,000 square miles for which an erosion control plan is required in Wisconsin.

3 Conversion to digital record based on scanning technology.

4 Using LANDSAT Thematic Mapper data.

5 Data format conversion only (already automated).

6 PLSS - public land survey section corner information from 1:24000 USGS Digital Line Graphs (assumes 50% cost share with USGS).

7 Production costs include analyses, computing, and plotting of seven maps for each township.

Without such a unified approach, DATCP must now deal with county plans which are based on varying sets of techniques and assumptions, and most of which cannot be directly compared or aggregated to state levels. The agency in fact has a staff person whose responsibilities include leading GIS program development. Unfortunately, this person spends the great majority of his time advising counties on many different systems and approaches that they have implemented, which curtails attention to overall and long term system compatibility.

A critical point in comparing the benefits of differing methods of soil erosion planning is that the GIS approach results in a database that can be tapped for further uses with little or no primary modification, although updating may be necessary. This is the commonly described "multipurpose" character of GIS databases. Besides Dane, some counties have used automated techniques, but their databases may be difficult to utilize for purposes much different from soil erosion planning. In the case of Dane County, development of further applications based on the existing data layers are already underway. These include nonpoint surface water pollution monitoring and tracking, field office management of federal agriculture program conservation provisions contained in the 1985 Food Security Act, and state Farmland Preservation mandates.

Another benefit to the GIS approach was conveniently demonstrated during production of the Dane County soil erosion plan. The flexibility inherent in the data structure and data processing software was exploited when a change in rules governing the federal Conservation Reserve Program occurred just as final map products were about to be produced. With the investment of less than an hour of one person's time to modify several parameters in the digital model, new graphics and tabulations were generated that reflected the new rules. In addition, locations and totals of the acreages affected by the rule change were available.

Technological change and adaptations based on existing technology can have significant impacts on costs and benefits. And these new opportunities can develop over short periods of time, so awareness of potentially emerging alternatives or innovations may accrue to major advantages. In the process of investigating, developing, and assessing techniques for automated soil erosion planning in Dane County, orders of magnitude improvements were recognized and implemented in several different respects. Work in the areas of geoprocessing, geopositioning, and remote sensing each yielded large gains (Chrisman et al, 1986). Reliance on any technology can be a two-edged sword, however. A current example is the uncertainty over future data from American satellites collecting resource data (i.e., LANDSAT) in a form and with a specific information content upon which particular applications may have been built (Matlock, 1987).

5.2 Designing an Analysis

The examples above indicate that significant resources are typically expended to maintain land records regardless of their format, but that the costs and benefits of different methods are not easily recognized, measured, or compared. If one is implementing a single purpose application project, economic analyses can be applied more directly; but many long term and multi-faceted activities are candidates for GIS automation. Performing economic analyses in these cases is much more problematic. A long list of considerations needs to be addressed(Wunderlich and Moyer, 1984; Epstein and Duchesneau, 1984). These include start up costs (hardware, software, facilities, and personnel), initial data acquisition, interpretation, and database loading, hardware and software maintenance and upgrade, continuing education for staff, direct and indirect user benefits, database maintenance and update, data sharing, and associated costs such as establishment of a geo-reference system, update of existing maps before digital conversion, resolution of source discrepancies, adjudication of

disputed information, and development of institutional mechanisms for establishing and maintaining this entire operational system.

Additional factors may be critical in more fully assessing the broad economic significance of GIS. Adequate baseline information would provide perspective on the benefits and costs of traditional methods. And availability of longitudinal studies of comparable implementations could be a key to valid long term assessment of a given GIS.

It has been estimated that by the year 2000, $90 billion will be spent on computing technology which supports public utility infrastructure alone (Automation, Inc. Newsletter, 1986). Even without adding the public and private investments in automating spatial data handling, this amounts to a large projected investment. Direction of this investment toward effective means for maximizing benefit cost ratios over relatively short time periods should result in more efficient allocation of public resources, and potentially, a better base of information for guiding societal decisions.

6. RECOMMENDATIONS FOR A RESEARCH AGENDA

A well developed methodology for evaluating the costs and benefits of alternative techniques for providing spatial data to an array of users should be a major goal of researchers focussing on GIS. Professionals involved in spatial data collection and use need to be aware of the ultimate applications of their work; an explanation of this sort, for surveyors and mappers, was offered by Epstein (1986). Techniques need to be developed which go beyond the avoided cost models to integrate benefits arising from the new capabilities which are possible only through use of a GIS, as compared to the simpler automation of existing manual methods. And economic aspects need to be kept in broad context, such as that suggested by Clapp et al (1985), wherein each aspect of GIS—from hardware and software, to the ultimate application of information to social needs—is evaluated in terms of its ultimate contribution to basic social goals.

Specifically, the following should be addressed:

- document the benefits and cost of traditional methods
- initiate and maintain longitudinal studies
- develop theory and models tailoring benefit cost analysis techniques to a broad view of GIS
- track the impact of emerging and prospective technologies
- measure costs and benefits of diverse pilot projects, including long term maintenance issues

The research agenda should include a focus on methods that can address the benefit/cost aspect of the GIS universe. Studies of investments in computing at the state and local level, and the public utilities, have been funded by NSF, the vendor community, and professional organizations such as the International City Managers Association (Kramer et al, 1986; Scoggins et al, 1985; Automation, Inc. Newsletter, 1986). Yet the benefits in GIS context from these investments are largely unknown,

and not clearly identified as being equally important to the investments. A balanced and effective research program must include these relevant factors.

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Implementing GIS Technology for Federal Land Management Tasks - Turning the Dream Into the Reality

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ABSTRACT

The Bureau of Land Management (BLM), which manages the largest amount of Federal lands, has used Geographic Information System (GIS) technology for ten years. It has closely examined how to apply the technology to its day-to-day tasks, using the standard methods of developing automated systems. The key factor in successful implementation in the "real world" has been the emergence of individuals willing to translate between the computer experts and the land managers. As a result, BLM has focused less on technical research or tracking the rapid changes in GIS technology, and more on implementing the tools already available that meet the BLM needs. The marketing process for new products in the private sector is a model for shifting the GIS emphasis from R&D to implementation.

I INTRODUCTION

Panacea was an ancient Greek goddess of healing; she could cure what ailed you. In her latest incarnation she has returned - as "GIS."

Geographic information systems (GIS) technology may be the panacea for Federal land management. GIS certainly looks promising, in an era where an ever-increasing workload is not matched by ever-increasing budgets or personnel.

In the relatively long history of GIS in the Bureau of Land Management (BLM), an agency which has proven its support for GIS by major commitments to it since the start of this decade, GIS is now used as an operational tool that helps get the job done. We have graduated past the point where GIS R&D was so fundamental, and automation so necessary, that any project was worthwhile.

At one time virtually any GIS demonstration would yield new possibilities for the use of the technology. Then the selection of GIS capabilities was limited, any research project was probably worthwhile, and the distinction between basic vs. applied research was irrelevant.

In the "good ol' days" it was good enough for an R&D project just to demonstrate the potential of the GIS concept. The computer technology might be too expensive at the moment, or the remote sensing system that was sufficiently accurate for data capture might be still a few satellite launches away, or the users might be resistant to change - but the completed R&D project would be evaluated as at least "warranting further study" because it showed what could be done.

Now the "further study" has also been done, to a large degree. Innovators in BLM have produced operational capabilities in daily use for such typical land management activities as:
- developing resource management plans
- identifying natural resource impacts of proposed actions such as approving a timber sale or drilling an oil well

- identifying potential drainage of Federal oil and gas resources by wells on adjacent parcels
- locating previously unidentified cultural sites through computer models
- determining suitable firewood cutting areas where the people can cut on the hillside above the road and not have to haul the wood up to the pickup truck.

These innovators have been the "champions" of implementing a new way of doing business, despite all the impediments a bureaucracy offers to change. In BLM these innovators have come from a variety of backgrounds, but all until recently have had both sufficient computer expertise and land management experience to serve as a translator between the two fields. They have been able to talk the language of the typical BLM field manager without confusing him with technical jargon, while later talking detailed computerese to programmers to specify exactly what capability was required.

It is unlikely anyone will ever document their individual performance, as has occured with the inventors of the computer industry,[1] or publicize the struggles between the innovators and bureaucrats as has been done recently in the automobile industry.[2] However, the central managing agencies in the Federal government, especially the General Services Agency (GSA) and the Office of Management and Budget (OMB), are now emphasizing the value of such translators and creative leaders as critical to successful implementation of new computer capabilities.[3]

The innovators' success has changed the ground rules of the GIS game. It still takes forward-looking people today to implement the GIS capabilities, but now these people may be far different from the technically-qualified ones who worked with the GIS programs in the past.

II GOOD R&D DOES NOT MEAN IMPLEMENTATION OCCURS

In Marketing High Technology: An Insider's View William Davidow distinguishes a "device" from a "product." Only when a technical invention, a device, can be easily sold and used does it

become a valuable item, a product. From his marketing perspective he asserts, "Great devices are invented in the laboratory. Great products are invented in the marketing department."[4]

Turning the technological capabilities into products is the challenge for GIS R&D and implementation today. The GIS concept has been sold; the basic technical development and demonstration is done. The issue has broadened from "What can I develop?" to "What do they need?"

The difference in pronouns in that last sentence is intentional. The shift in approach may not be wecomed by those responsible for the success of GIS to date. The recent career changes of the co-founders of Apple Computers, Inc., are perhaps the most obvious example of how achievement in the technical development field does not ensure continuing success in managing implementation. The people so successful at device creation may in fact resent the salesmanship of the product creators and resist the shift in emphasis.[5]

The result is that company product development or government agency R&D can be misdirected, when a gap develops between those with projects underway and those with a need to be met (also known as customers, or users). That's not so dramatic a revelation, I know, but I suspect it's a rather unsettling realization in the arena of at least Federal GIS development.

In the last decade the development of GIS has been exciting for those responsible for managing vast tracts of Federal land. BLM is the Federal agency with perhaps the greatest application for GIS technology for land management applications. It is responsible for 334 million acres of Federal surface and 727 million acres of mineral estate, the largest such acreage managed by one agency and totalling nearly one third of the United States.[6] Not so long ago, any investment in GIS development was expected to yield a major improvement for BLM over the old way of doing business.

The old way has been based on hard-copy maps since the Northwest Ordinance of 1785. Duplicate sets of records have been

required so different offices would have access to basic information on who owned what property rights, or what resources would be affected by a proposed action. Many of the 1987 office procedures and tools (plats and maps drawn by hand, case files bulging with paper, etc.) are little advanced from the early 1800's.

Before GIS technology was identified as directly applicable to BLM's tasks, other modern technology was used with varying success. Most computer programs were directed at administrative functions such as payroll processing, and bar codes have been implemented as a means to track the thousands of case files in some offices.

For managing resources using spatial relationships, aerial photography has been a key tool, especially for such activities as planning a timber sale in Western Oregon. Landsat imagery has been explored as well. However there appear to be more devices than products in this area, compared to the aerial photography or GIS.

The difficulty in using Landsat vs. photography illustrates the problem in GIS management today. The photography clearly met a customer's need, and funding for overflights of the commercial forest region has been provided regularly as a result. The Landsat imagery suffered from the lack of detail available, before SPOT at least, and the R&D produced some products (in the late 1970's, for example, BLM located through albedo differences some coal mines in Alabama that were potentially in trespass) but with a high ratio of devices as well. As a result funding has been, well, "spotty."

As Davidow notes, "The cost of creating a complete product is often many times the cost of developing the device."[7] The development phase of remote sensing imagery is not completed and it may be premature to judge the product - "further study is warranted."

GIS technology, on the other hand, has already evolved to the point where products are readily available for performing a variety of tasks. As you know, companies are marketing full GIS

solutions to the problems of their customers, such as utility companies or local government planning offices. Products are available for different market niches, from medical imaging to surveying.

GIS has emerged from the laboratory and, based on the number of visitors to BLM from foreign governments, will soon spread all over the world in one fashion or another. While basic research will continue to develop "new and improved" GIS capabilities, we are fast approaching the point where the new capabilities will be refinements of the old ones rather than dramatic technical breakthroughs comparable to the first multi-spectral scanners, vector-to-raster conversions, or polygon overlay routines.

However, the spread of GIS applications across the world or just throughout one Federal agency will not happen if GIS technology is left to its own devices. To fully apply GIS technology to where its use is routine in day-to-day operations, some high-tech marketing remains.

III IMPLEMENTATION - A NEW APPROACH

GIS technology provides new tools to do land management (and other) jobs faster, cheaper, more accurately, whatever. That has been the basis for its development from the beginning.

Those responsible for nurturing the technology to this point, the sponsors and champions of new ideas and new ways of doing business, have succeeded in creating a wide variety of GIS devices and sufficient products to establish a continuing base of R&D funding. Enhancements of basic capabilities are created regularly now.

We are now past the basic research. The continued development of GIS through R&D will be primarily to differentiate the GIS products from one another, specializing in applying them to the jobs at hand more effectively than some other GIS tool developed by someone else.

We are graduating past the basic acceptance level as well, into more detailed user specifications for the GIS tools to be developed. The model for the implementation of these new tools is no longer the technically-oriented, government-funded R&D project, where a new GIS capability is created, demonstrated, determined to be useful based on the concept or potential, adopted, and refined.

The new model for the continuing implementation of GIS is probably the private sector's marketing process. Implementation of new GIS capabilities can be treated just like introducing new laundry powders for grocery shelves - both are products that improve on existing ones.

This approach involves an entirely different culture, with presumably less cooperation between GIS developers and more advertising of the marginal benefits of one product over another. Product development and marketing is perfectly accepted in the private sector. When applied in the Federal sector, however, it creates at least the appearance of inefficiency. Legitimate corporate rivalries in the private sector are an unacceptable model for tax-supported agencies, and politically it is rarely acceptable for an agency to declare bankruptcy and go out of business because someone else met the market need better.

Despite concerns about inefficiency it is obvious that "turf" concerns still thrive in government. As GIS development matures, it is realistic to expect such concerns to have more effect on the R&D efforts and implementation. The OMB has established several mechanisms to minimize this potential for GIS development, primarily the A-16 process for coordinating data collection requirements for map production and the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC).[8]

Both require a recognition that the development and data collection are not ends in themselves, but instead a means to meet a particular set of needs. "Find a need and fill it" is the old marketing maxim. For GIS R&D to be well targeted to yield products rather than devices, the mechanisms by which those needs are identified and met are growing in importance compared to the technical R&D.

In a sense, identifying user requirements (or a market niche) has always been a legitimate part of R&D. For GIS in the Federal sector, however, the needs have been so great and the technical successes so dazzling lately that the market research has been rather muted in comparison to the hardware and software research.

The mechanisms of determining user requirements (or market niches for positioning products) are basically two: analysis and insight.

User requirements in the private sector are most clearly seen in retail sales companies, where the customer either purchases the product or does not. Computerized sales records now permit rapid analysis, with expensive crunching of the numbers for the sales data thanks to point-of-sales terminals and telecommunications networks permitting daily review of "what's hot." Through such analysis companies such as Radio Shack can avoid being stuck with a large supply of surplus products when the fashion shifts, as Atari was when the demand for computer game cartridges collapsed several years ago.

In the public sector, a variety of analytical processes exist even though there may be no equivalent to the sales data. These processes, such as basic structured methods analysis or IBM's Business System Planning, examine the mission of the organization, the tasks necessary to perform that mission, the data needed to complete each task, and the improvements possible by automating these tasks. Benefit/cost analyses tend to become the determining factor in deciding what investments to make in meeting the user requirements, at least in theory.

The track record for using such processes is far from perfect. It is not unusual for intuition to be the key basis for a decision in an agency, and for the analysis to be steered to justifying that decision. This may well be a wise approach, if a little confusing to those who think government actually works the way we were taught in the ninth grade.

Insight by forward-looking managers and technical personnel has enabled the GIS technology to become so capable today. However, I predict the utility of insight as the basis for GIS R&D will decline in the next few years, and the analytical techniques will gain in importance. The easy challenges, the basic needs that anyone recognized as worth meeting through investing in GIS R&D, are fast coming to an end. Success has narrowed the obvious opportunities to do further research. Now a proposal must be more targeted to meet particular needs than before.

This may well be in contrast with the trend in the private sector, where it seems the reliance on quantitative market research is fading compared to using intuitive approaches with focus groups.[9]

If you accept my premise that the basic GIS research has been largely completed and the next several years will be primarily product differentiation, based on finding a need and filling it, then we face the same challenges as the marketing groups and advertising agencies for cars and groceries.

If so, then we need to steer our GIS R&D and implementation efforts to identifying those needs, not developing more efficient devices, to ensure we generate products for which there is a demand. GIS technology is too valuable a tool for us to relegate to the labs; we can not afford to allow its outputs to sit on a shelf. If we are to manage effectively, we may have to look in odd places like the marketing literature for assistance in implementing it - but the GIS potential is worth it.

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SUCCESS CRITERIA FOR GIS

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Organizations planning or in the midst of implementing geographic information systems (GIS) are confronted with many technical, financial, organizational, and personnel challenges. This is true for such varied organizations as government natural resources and environmental regulatory agencies, public utilities, forestry companies, municipalities, and energy companies. To a large extent, organizational concern about GIS success focuses solely upon technical factors (e.g., data capture techniques (scanning vs. digitizing), spatial data structures (raster vs. vector vs. polygon vs. topological), software "toolkits" (ARC/INFO vs. MOSS vs. Intergraph vs. Synercom), or database structures or management systems (relational vs. hierarchical vs. quadtree vs. ORACLE vs. INFO vs. INGRESS). Although technical issues do play a significant role in the success of a GIS implementation project, financial, organizational, and personnel factors are just as critical and may have longer term impact on the project and system's ultimate success.

2. A DEFINITION FOR GIS SUCCESS

As mentioned in the introduction, GIS success is a function of technical, financial (or economic), organizational, and personnel factors. For the purpose of this paper, **GIS success is defined as the meeting of organizational requirements for the collection, management, analysis, display, and distribution of geographic/geographically-defined information commensurate with the level of investment over time. Furthermore, GIS success is measured by the degree to which it becomes integrated into, and a part of, an organizations overall information resources infrastructure over the long term.**

2.1 Technical Success

There are five significant components of GIS technical success; Software, Hardware, Data, Interfaces, and Technical Standards. Although the "answers" differ from application to application, all five components must be satisfactorily addressed to ensure long term success of the system.

Software. A great deal of time and effort is often spent deciding on which GIS software "package" to buy. There is no denying the importance and long term impact of "going with a specific vendor solution". Developing a "unbiased", successful request for proposals (RFP) is no small feat. However, before choosing one package or another, the first question to answer is whether or not a GIS "toolkit" is appropriate to your specific needs. The fundamental question is to what extent to your organization needs a broad set of generic capabilities which can be customized for a variety of applications. Conversely, are there a restricted number of spatial analysis or data management requirements which could be effectively served by developing specific algorithms optimized for solving these requirements? The former may justify a "toolkit" approach while the latter may only require a custom solution.

Part of the software question also revolves around the need for a true GIS which integrates tabular and spatial data in some form of spatial data model or perhaps the more limited requirement for a flexible computer graphics/ mapping capability. Assuming the need for a GIS persists, questions of types of data managers and structures, both tabular and spatial, become more important. Current experience suggests that relational data management systems linked with arc/node/topologically structured spatial data provides the most flexible, powerful set of GIS capabilities and provide a greater measure of long term system viability.

Hardware. The increasing power, lower costs, and blurred distinctions between hardware platforms (i.e., mainframe, super-mini, mini, super-micro, micro, graphics workstation) makes hardware choices both easier and more complicated. Its easier in the sense that more hardware, and more powerful hardware (in terms of memory, disk storage, MIPS, multitasking, and distributed processing) is available at costs accessible to large and small organizations. The difficulty is in choosing the right types of machines and configurations to meet current and growth requirements while satisfying software, data, and interface constraints.

Current experience and trends indicate that minicomputer file servers and microcomputer-based workstations in a distributed processing network provides the right mix of centralized data administration, local processing power, and applications "independence". Although this may not fit every organization's needs, the increasing power of desktop computers combined with networking and distributed database technologies is opening the doors to much fuller integration of GIS in the workplace. Above and beyond software/data compatibility, the biggest hardware success factor is found in bringing the power of GIS directly to as many users as possible.

Data. Data is the single most important aspect of any information system and this also applies to GIS. Operational software and hardware solutions can be bought "off-the-shelf", but for the most part geographic data acquisition requires individual development efforts. Data success depends upon the database development and acquisition strategy, data quality, data resolution, and data integration.

Successful database development and acquisition comes from taking advantage of existing sources of digital data (within or without the company), clearly defining minimal data requirements (i.e., data element justification), setting priorities either by data type (e.g., water bodies) or by geographic sector (i.e., collect all data elements and types within a quadrant), and effectively using available data capture techniques (e.g., scanning, digitizing, image processing, bulk data entry of tabular data at inexpensive alphanumeric terminals, etc.). Developing and implementing data quality assurance procedures will also contribute to data success. Knowing to what extent data can be used or depended upon, to make decisions or judgements, lends credibility to the "products" of a GIS and thus determines the degree of success. Capturing data at acceptable levels of spatial resolution is another data success factor. First determining what is acceptable spatial resolution (how much accuracy in geographic or spatial representation do we really require?) will have a direct impact on the type and amount of data required as well as the approach and ultimate cost of data capture. Finally, effective data integration plays an important role in data success. Bringing data

together in a consistent, logically linked framework helps to ensure the flexibility and long term viability of the database. Commercial database management systems make successful data integration easier to achieve and sustain.

Interfaces. GIS support for various levels of interfaces is a critical technical success factor. A minimum of four levels of user interaction should be supported; programmer, system administrator, applications or data analyst, and decision-maker. Programmers should have access to source code and data structures in order to make system/program corrections, modifications, or enhancements. System administrators require "tools" to monitor work flow, modify system performance (e.g., change user/program priorities), communicate with system operators, maintain efficient file organization and storage, and develop administrative logs and reports. Applications/data analysts require information-oriented interfaces which are graphical or tabular. These interfaces should focus on database contents, algorithm explanation, or model assumptions but not necessarily reveal the "code" behind the software or the specific data structures supported. The "highest" level of interface should be reserved for decision-makers. Here, natural language interfaces and use of graphics are paramount. Decision-makers are not concerned with the machinations of a GIS, only with access to information contained within, portrayed quickly and meaningfully.

Technical standards. Development and support for standards is emerging as a crucial technical success factor for GIS. Standards for graphics (e.g., Graphical Kernel Standard - GKS), database query language (e.g., Standard Query Language - SQL), telecommunications (i.e., TCIP or ISO), programming language (e.g., C, Fortran), screen interface (e.g., X-Windows) and data structures and formats (e.g., Digital Line Graph - DLG) greatly enhance portability of software, device independence, transferability of data and images, and reduce long term costs. Of course, concerns about performance and flexibility do need to be addressed and do present challenges to pure standards implementation. However, the trend, particularly in large organizations, is towards adoption of these or related technical standards.

2.2 Financial Success

Financial success of a GIS can only be judged in the context of the total life cycle. Any organization budgeting, planning, designing or implementing a GIS must understand, and make an acceptable level of financial commitment to the project, so that it is sustainable from requirements analysis, through definition and design, to implementation, documentation, training, database development, and maintenance. GIS is costly and typically more expensive than anticipated. If an organization is unable or unwilling to make a life cycle commitment, then an initial demonstration project or prototyping approach may be preferable. Even in these cases, costing needs to be carefully considered, and requirements or specifications must be made consistent with financial constraints. Establishing reasonable expectations among supporters and future users of the GIS may have the most significant impact on financial success. The "fixed" hardware and software costs for GIS are of far less concern, proportionally, than potential costs of database development, and the uncontrollable "needs" of users.

2.3 Organizational Success

GIS are (should not be) neither built nor operated in a technical vacuum. GIS must serve a wide variety of organizational needs and these often differ from one place to another (within organizations or between organizations). The fundamental characteristics of organizational success can be found in defining and meeting organization/user requirements, setting and meeting priorities, delivering GIS products and services as soon as possible, providing meaningful support to the organizations senior managers and decision-makers, and facilitating the organizational adoption of the GIS "psychology".

Definition of organizational and user requirements is most effectively achieved by pursuing a structured analysis of requirements through observation of existing geographic data management/analysis procedures, interviews, brainstorming sessions with key "players", and rapid prototyping where appropriate and affordable. Setting functional and database development priorities will greatly assist in more quickly delivering GIS products and services to the organization. This will produce tangible benefits and help sustain the political and financial support needed for full life cycle success. Another important factor in GIS organizational success is the degree to which the decision-making process is understood and how this influences the design and implementation of the GIS. The GIS must produce real products (e.g., maps, charts, tables, statistics, projections) which meet operational needs. It must also provide meaningful support to senior decision-makers to garner their long term commitment to the technology. Finally, supporters and developers of the GIS must assist the organization to adopt a GIS "psychology" which requires inter-disciplinary, inter-departmental, intra-organizational, and inter-organizational coordination and cooperation to fully realize its potential. This last component may be the greatest stumbling block to success because it is fundamentally a human/organizational challenge.

2.4 Personnel Success

GIS will only succeed when competent, well trained, committed people are involved. This seemingly obvious statement deserves serious attention by any organization contemplating GIS development. Experience demonstrates that a mutli-disciplinary team possessing technical and substantive expertise is required to successfully implement a GIS. Creating such a team out of existing personnel and new hires is a significant challenge and a fundamental prerequisite to commencing a GIS development effort.

GIS development team participants require as a group a wide range of technical knowledge as well as intimate understanding of the application requirements. The team must be able to effectively address the critical success factors identified above and focus this knowledge on serving the expressed interests and needs of the user community.

Personnel and organizational success are obviously high intertwined. However, focusing on the specific personnel requirements of a GIS project apart from the broader organizational requirements is important. Deciding whether a specific department or a new group will be formed to develop the GIS may have profound implications on the success of the development effort as well as on

the ultimate disposition and use of the GIS. Pulling individuals from all parts of an organization may be the best approach. Getting as many people and offices of an organization to contribute to the building effort will help to ensure long term cooperation and commitment to a life cycle success.

3. SUMMARY

GIS success depends on technical, financial, organizational, and personnel factors. GIS requires good planning and a commitment to the complete life cycle of design, development, and maintenance. Understanding organizational/ user requirements, identifying constraints, and setting functional/database priorities greatly contribute to successful implementation. Quickly bringing tangible products and benefits to the organization and principle supporters of the GIS will help ensure the financial and political commitment necessary for long term growth and viability of the system.

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CRITICAL MANAGEMENT AND TECHNICAL CONSIDERATIONS WHEN PLANNING FOR A GIS ACQUISITION

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ABSTRACT

This paper provides a short GIS overview and discusses key considerations that must be addressed by program management when planning for a GIS acquisition. Management considerations are addressed first, then technical considerations are presented. Finally, this paper concludes with key questions which can help focus attention on the critical management and technical issues in GIS implementation. The considerations presented in this paper do not constitute a final "cookbook" detailing how to implement a GIS. The considerations do, however, present a good starting point for further refinement as an organization makes progress in developing an overall GIS planning and implementation strategy. This overview draws on the experience gained from several planning projects conducted by the author with large Federal agencies desiring GIS technology and smaller government organizations interested in integrated Land Information Systems.

1. INTRODUCTION

Modern data management and analysis practices now rely on a wide variety of computer hardware, software, and telecommunications equipment. This document focuses on a specialized set of data management and analysis tools, called Geographic Information Systems (GIS), which have the potential to enhance program management and decision-making. GISs are decision-support systems that can use spatial data to support interdisciplinary studies and facilitate analysis with unique data integration and display functions. The purpose of this document is to serve as a guideline both for managers who want to determine whether a GIS may be appropriate for their program needs, and for managers who are "sold" on GIS technology and wish to develop a specific GIS application.

2. GEOGRAPHIC INFORMATION SYSTEM OVERVIEW

Geographic Information Systems provide data input, storage, manipulation, analysis and display capabilities for geographic, cultural, political, environmental and statistical data in a common spatial framework. The data analyzed are a collection of spatial information (represented by points, lines and areas) and their associated attributes (characteristics of the features which the points, lines, and polygons represent). Examples of point data may include drinking water wells, dams, monitoring stations, and mountain peaks. Lines are commonly used to represent rivers, roads, or contours. Soil classes, crop types, political jurisdictions, and drainage basins are represented as area or polygon data. Some sources of data for GISs include maps, aerial photographs, censuses, crop records, field notes, satellite photos and meteorological records.

The advent of sophisticated computers with mass digital data storage devices has facilitated the integration of spatial data analysis, statistics, and computer graphics into comprehensive "turnkey" geographic information systems. GIS technology bridges the disciplines of computer science (e.g., image processing and pattern recognition), information management, cartography, and environ- mental management. The geographic information system is distinguished from other forms of information systems by its ability to perform spatial analysis.

There are many kinds of GIS turnkey systems. Some overlap exists in terms of their capabilities. Since technology and software are constantly changing, it is probable that vendors will be able to add extra capabilities without adding substantially to prices in the near future. One significant technology change during the last several years has been the availability of microcomputer-based GISs. These systems, although limited in terms of algorithm capabilities and computer processing speed, offer viable alternatives to the more expensive mini and mainframe systems. Selection of an appropriate system or collection of software tools must be linked to spatial data analysis needs.

2.1 Spatial Data Features

The geographic location of each data item (or "attribute") is a key identifier used to describe and organize data in a GIS. Maintaining the integrity of this spatial descriptor as part of the data base record permits normal data base management system operations and adds the capability to manipulate and analyze data geographically. The concept of data analysis in relation to geographic position is commonly encountered in map reading. Conventional maps are used in environmental analysis and natural resource management for numerous purposes.

One frequently used analytical approach is to assign colors or patterns to multiple map themes and overlay them with colored transparencies to reveal spatial relationships. This process of overlaying maps is a major function of a GIS. GISs also provide other analyses, including cross tabulations of data, attribute selections, boolean combinations, modeling and customized displays. For example, a map of water well locations may be digitized using an x, y cartesian coordinate system. Well attributes such as depth to water, depth to bedrock, water quality per 100-foot increments or well diameter may be attached to each well record in a relational data base. The GIS can then generate maps and associated tabular reports for unique subsets of the data (e.g., only wells located in areas where the aquifer surface is less than 200 feet deep, with a salt content greater than 1200 ppm, and within 500 feet of each other).

Geographic data can be represented using either of two formats -- raster/grid or vector/polygon data structures. Raster/grid data refers to attribute values and spatial references tied to specific x, y intersections or grids in space (e.g., latitude/longitude). Fine grid spacing allows high resolution, and good definition of spatial characteristics. Scale is also important in grid spacing since large scale (small area) studies require higher levels of accuracy and finer grid spacing. In contrast, small scale (larger area) studies do not require rasters or grids in such fine detail. Vector/polygon data structures, on the other hand, describe unique lines or forms of geographic features. A lake, for example, can be described by the coordinates which comprise the circumference of the outer lake boundary and can be captured

and stored in the GIS as a "tracing" of these features. The geographic attributes of the lake may remain constant even as the resolution of the lake boundary coordinates changes.

The advantages of raster/grid data structures over vector/polygon structures include low cost for computation, ease of comparison between data layers, and relative ease of data overlaying to generate integrated data sets. The benefits associated with vector/polygon data structures include enhanced spatial accuracy, more "correct" feature descriptions, and compatibility with traditional paper map descriptions of geographic features. The difficulties encountered with vector/polygon data structures include more complex computational requirements (with concurrent higher costs) due to increased geometric complexity. Consequently, some GISs have the capability to handle both data structures, while others are restricted to only raster/grid or vector/polygon.

2.2 Data Input

The data entered into a GIS often include spatial data from maps, remote sensors (aerial photography and satellite imagery), and environmental monitoring. GISs require entry of two distinct types of data: geographic references and attributes. Geographic reference data are the coordinates which describe the location of spatial information. This type of data entry usually occurs via a process known as digitization. A special peripheral device -- a digitizer -- is used to convert a drawing or map into a digital format. Most GIS projects require a large digitization data input process consuming many man-hours of effort. Attribute data entry (e.g., water quality parametric values) often occurs via key-entry at a terminal, reading a magnetic tape, or downloading from a separate computer system.

Since data which form the GIS data base often come from different sources, and since digitization may be done by staff with varying levels of skill, most GIS data base development efforts involve extensive levels of data validation and quality assurance. An initial and ongoing commitment to data quality is generally rewarded by confidence in the graphical and analytical results of the GIS.

2.3 Data Base Management And Data Storage

The characteristic which distin- guishes a GIS from other data base management systems and manual map overlay procedures is the way a GIS stores the spatial data and makes it available for user access and analysis. Derived maps and data sets may become part of the GIS data base in a feedback process that permits future retrieval and display without rerunning the analysis procedure. These map and data layers can be superimposed during analysis to produce various map products with the GIS information display functions. This data generation process requires special spatial analysis and tabulation capabilities provided through the data base management system. Since the analysis and processing limits of each GIS vary from vendor to vendor, the anticipated analytical methods and data base management requirements should be well understood before selecting a particular system.

Efficient data storage organizes the spatial data in a format which permits rapid and accurate updates and corrections to the data base. Data storage refers to how the data formats and structures are supported during data opera-

tions. Frequently a data dictionary is used to organize a data base and record information about the geographic and attribute information in the system. Some of the information stored about data bases includes data structures, formats, and access methods. Data dictionaries can be very helpful and important tools, especially for managing active and growing geographic information systems.

2.4 Data Manipulation And Analysis

The GIS data base management system provides the ability to query, manipulate, and extract both geographic reference and attribute data. One of the major functions of a GIS is the analysis of multiple layers of data in a selected geographic area. With a GIS, standard statistical manipulations of attribute data are possible, as are boolean queries of attribute data files, generation of mean and standard deviation for numerical data ranges, and classification of data into mappable units. Other GIS data manipulation and analysis capabilities include querying unique spatial distributions of data and asking questions about data to display the unique spatial arrangements which meet a specific criterion.

2.5 Information Display

Information display includes the representation both of raw data and of the results of data manipulation and analysis. Outputs fall into several categories: maps, charts, graphs, surface models, listings, and hybrid representations. The form in which outputs are presented (medium of presentation) also varies, and includes: CRT images (monochrome or color), color slides (from virtual images or directly from graphic bit planes), film plots (print-ready masters), video disk images (requiring digital to analog image conversion), floppy disks of digital image data, microfilm (or "fiche") copies of graphic images, or printed hard copy graphics.

It is important to realize that outputs (as described above) are distinct from spatial analysis. Geographic/ spatial analysis of data usually precedes data display, although initial display of "raw" data can serve as a useful hypothesis tester for attribute and/or spatial data analysis. A comprehensive geographic information system supports various computer mapping/graphics peripherals that provide most of the types of outputs described above.

3. MANAGEMENT CONSIDERATIONS

Organizational management planning a GIS implementation need to: define applications and objectives; determine the scope of the GIS applications; identify existing data sources; determine staffing requirements; establish data validation measures; estimate life cycle/staffing costs; and establish GIS standards.

3.1 Define Applications And Objectives

Initially, a thorough evaluation of GIS needs is required before attempting to acquire a system. Identification of how program activities and decision-

making will be improved with GIS tools is mandatory. A thorough analysis of needs requires answers to the following questions:

- o what agency activities will be supported by the proposed GIS activity?
- o how will these program activities be supported?
- o what are the anticipated benefits of these GIS activities (timeliness, workload, and enhanced management)?
- o how can these GIS applications also provide cross-program assistance?

3.2 Determine the Scope Of The GIS Applications

In beginning to plan a GIS implementation, management should define the scope of its GIS needs relating to the:

- o number of anticipated users;
- o number and types of decisions to be supported;
- o geographic and programmatic areas to be covered; and
- o types of data required

These are among the crucial decisions which set the scope of the GIS application and determine the utility and versatility of the final product.

3.3 Identify Existing Data Sources

The geographic boundaries and scale of data required in the proposed GIS program need to be detailed. They must be considered in conjunction with the types of data that will be used in the system and the status of these data. Some of the data will probably already exist in computerized formats, while other data will be manual files in a variety of conditions (e.g., hand-drawn maps and technical reports). The manual files will have to be computerized using the GIS software/hardware (e.g., digitizer), while the computerized files will have to be converted to the GIS format. In addition, datasets must be reviewed to determine which files/fields need to be computerized and which ones, if any, can be eliminated. During this dataset inventory phase, identification of requirements for entirely new data should also occur. It is expected that the program will be able, in a parallel fashion, to describe these datasets in detail and provide a synopsis of their expected use.

3.4 Determine Staffing Requirements

The organizational environment in which the GIS will function depends on the existing ADP support services and potential for incorporating the GIS into an existing ADP support structure. For example, the choice between the use of a stand alone dedicated system versus one that is "added on" to an existing computer system will change the staffing level and expertise required. Personnel required to operate the GIS may include computer system managers, computer operators, data analysts, programmers, supervisors, environmental

scientists, cartographers, and specific program experts. Typically, full-time computer system managers and/or operators will be needed for mainframes and large minicomputers. The number of technicians required will depend on the amount of processing to be done, budget constraints, and time allocated for completion of the initial database.

It is extremely important to also have on hand computer-literate program management staff who are experienced with organizational responsibilities and requirements. GIS projects are multi- disciplinary in nature, and are most successful when developed by multi- disciplinary teams.

Another area requiring guidance may be GIS training. Centralized GIS training may prove to be a useful and cost-effective strategy for disseminating specialized GIS knowledge to organizational offices. In contrast, it might be more cost effective to support sending staff to special training programs offered by the private sector and academia.

3.5 Establish Data Validation Measures

The issue of data validation must be addressed in the early phase of GIS data base planning. Program managers must determine if incorporation of existing QA measures for already existing data is sufficient. Furthermore, QA standards will also have to be established for newly acquired data. Data acquired from other data bases should always be thoroughly examined to reveal QA problems.

The quality assurance procedures for each GIS application must reflect a conscious decision, on the part of management, as to the level of data quality necessary to support decision- making. Required levels of data quality can vary, depending on the decisions which the GIS will support. Quality indicators in the GIS data base or fields which identify data sources should be considered as means of improving quality assurance.

3.6 Estimate Life Cycle/Staffing Costs

The implementation of a GIS system includes numerous costs associated with equipment purchase, installation, database development, etc. In estimating costs, the managers must pay particular attention to software and hardware prices and the additional costs of: upgrade of CPU or purchase of new CPU to support GIS applications; shipping of hardware; modifications to existing hardware or purchase of new hardware; site preparation and installation; training; quality assurance; data gathering and updating; supplemental utility programs; regular maintenance to both hardware and software; and system upgrades.

A realistic estimate of required staffing and associated budget costs is also necessary. It is helpful to convert staffing requirements to hourly costs. For example, a 40 man-year effort to create the working database can be accomplished over a four year period with 10 programmers/analysts or over 10 years with 4 programmers/ analysts. The total staffing costs will vary significantly between the two scenarios.

3.7 Establish GIS Standards

Another strategic step is the development of GIS standards. Whenever possible, previously established standards should be followed, but the unique characteristics of GIS technology will require establishing additional standards. Standards can be required for: digital spatial data organization; georeference definitions; interchange formats; feature type definitions; and data quality.

In some cases, it will not be appropriate to promote standards but rather provide guidance. A common practice is to use ANSI software standards to ensure long term viability of GIS software in a dynamic technological environment.

4. TECHNICAL CONSIDERATIONS

A number of technical issues must also be addressed while planning for GIS implementation. This section highlights the following key technical considerations:

- o Data acquisition
- o Data input
- o Data access, manipulation and analysis
- o Data validation and quality assurance
- o Data updates and maintenance
- o Storage requirements
- o User access and security
- o Technical environment

4.1 Data Acquisition

Data loaded into the GIS may come from a multitude of sources. These data may have been newly collected or acquired from existing data bases. In either case, decisions will have to be made concerning quality assurance of the data before incorporation into the GIS.

The spatial data used in the GIS will contain attributes such as raw data values, test scores, or indices that must meet GIS data input formats. In addition, the spatial data itself may be in the form of published maps, printed tables, digital map attributes or digital tabular files. Incorporation of data attributes such as source, scale, projection, geographic location, year of acquisition, and reliability must be defined and standardized prior to data loading.

4.2 Data Input

The method of data input can include downloading, digitizing, scanning and keyboard entry. The selection of a data input process should be tailored to the volume of data requiring input, the peripherals supported by the GIS, and manpower and time constraints. Digitizing requires many man-hours of tedious work and establishment of input protocols to maintain acceptable data quality standards. Loading data into the GIS from other data bases is often complicated by a need to reformat the data to comply with the host computer or GIS data record format. Graphic data is commonly the most difficult data to

reformat. Anticipation of format conversion needs is required for realistic GIS data input planning since format conversion represents substantial levels of effort by programming and technical staff. When data are acquired from manual files of historic or newly collected spatial data, and then automated in-house, the data input process is generally less complicated because data formats are well understood.

4.3 Data Access, Manipulation and Analysis

Data access and manipulation functions permit retrieval of specific data by any attribute or combination of attributes. Well-designed DBMS software generally provides these capabilities by using existing structured queries. However, custom queries are often needed and require DBMS software modification.

A map library should provide rapid indexing to all digital maps within the data base. This library can be maintained as an on-line index and provide the user the capability to query by project identification, geographic area, or place name. The need for a map library increases as the size and complexity of a GIS data base grows.

Use of a data dictionary will assist in maintaining an inventory of map and other spatial data sources used in the GIS. A description of data attributes for each map, photo, or image used in the GIS data base can be catalogued and described in text form. Additionally, quality assurance standards can be included in the data dictionary. Experience shows that insufficient documentation may handicap GIS operation.

Data manipulation can also include tabular and graphic display of the GIS data. Tables and listings may be displayed and printed on CRTs, printers or plotters. Data display is an important step for data base verification and subsequent data analysis.

GIS data analysis requires extensive computer processing for calculating areas, distances, buffers, volumes, overlays, frequency occurrences and Boolean combinations. The power and flexibility of the GIS become readily apparent during these analysis processes. Proper data base design will fulfill user expectations and avoid disillusionment.

Modeling of spatial data is often an important program analytical need. The GIS may contain modeling algorithms, or modeling may be conducted in an independent external computer environment. When using a separate system for modeling, results can be incorporated into the GIS through the input methods discussed above and retained as part of the GIS data base for other analysis objectives.

4.4 Data Validation and Quality Assurance

Data validation ensures that acquired data meet acceptable data quality standards and quality assurance (QA) maintains data integrity throughout GIS data processing. The spatial data incorporated into the GIS must be verified to ensure proper formatting. Using reformatted data increases the risk of data conversion errors. Program management and GIS staff must determine what level of QA is needed for acceptable data quality. This determination

dictates what data validation processes are required in the GIS. Data quality standards must be maintained throughout data retrieval, display, analysis and modeling functions. During data retrieval and display, mechanisms for detecting errors in base data can ensure improved data quality. Additionally, QA algorithms can be used to check erroneous data ranges and values. It is also necessary that data maintenance activities employ QA standards (e.g., scheduled backups).

4.5 Data Updates and Maintenance

A GIS is a dynamic decision-support system that requires data updating and revision. Updates should not be confused with data validation corrections that are associated with QA actions. Updates are provided to maintain the currency and utility of the data base. Changes to the GIS data records should only be permitted by authorized staff. Scheduled updates should occur during specified periods to reduce the possibility of inadvertent alteration of the data base. Proper data maintenance requires the periodic system backup procedures common to all ADP installations.

4.6 Storage Requirements

Realistic understanding of data storage requirements is important to the long term success of the GIS effort. Disk storage provides the most accessible but most expensive form of data storage. Often in a multiple hardware/software environment, disk storage becomes limited by growth in users and data bases. Tape storage is often a viable alternative but problems may be encountered with physical storage demands and tape reading delays. Tapes quickly fill limited shelf space and may become a major handling and storage task. Additionally, there are certain risks associated with the transfer of information from disk to tape -- losing or misreading records is possible.

Alternative mass storage devices such as laser disks may relieve some of the on-line data storage bottlenecks. However, this is a relatively new technology, and is not an available add-on option with all GISs. These storage requirement issues should be addressed during both the management life cycle planning and the technical requirement phases of GIS implementation planning.

4.7 User Access and Security

Potential users include GIS staff, program managers, institutional users, and the public. Data base access should be carefully evaluated to determine the level of data base access each user needs. The ability to update, copy and delete data is not needed by all users. Restricting certain users to "read only" privileges is sometimes appropriate. Those users who manage the GIS and are involved with data base development should have a high level of access.

4.8 Technical Environment

Numerous hardware and software requirements must be specifically identified according to the program activities to be supported, such as:

- o Amount of computer memory and storage required;

- Number and kinds of peripherals needed;
- Size and number of data sets to be incorporated into the GIS;
- Ability to use existing operating systems, and add-on software/hardware; and
- Predicted software/hardware demand by task and program (days per week, hours per day).

Furthermore, if the GIS is to be created by adding software and peripherals to an existing computer, additional requirements for data communications and device compatibility may include:

- Multi-user support and the ability to expand the number of ports as user demands grow;
- The ability to access data in a timely fashion (either batch or interactively), perhaps via remote workstations; and the
- Ability to support multiple graphics output devices of different types and makes (e.g., plotters, graphics terminals, printers).

5. CRITICAL MANAGEMENT AND TECHNICAL GUIDANCE

A well planned management approach for implementing GIS technology is necessary for ensuring successful GIS program applications. This series of questions and corresponding discussion is provided to help program managers focus on critical management and technical issues associated with GIS implementation.

1. <u>What types of data should be entered into the GIS, and what additional data should be collected?</u> Just because certain types of data have been collected does not justify their entry into a database. Furthermore, the gathering of new types of data should not occur merely because a new tool is available to process that data.

2. <u>Should database development be performed in-house or contracted?</u> Contracting has several advantages: the database may be completed sooner, funds for contracting may be more readily available than manpower, and contracting the digitizing may alleviate the need for data entry hardware and/or software. However, when digitizing is performed by a contractor, any errors on the maps given to the contractor will find their way into the digital database. If users familiar with the data do the digitizing, such errors may be caught prior to digitizing. Also, in-house digitizing produces trained operators, making the tasks of updating and editing less difficult.

3. What type of data validation needs to be incorporated into the creation of the data base? Data validation is a matter often confronted in the justification and implementation of a GIS. The process of computerizing information will often reveal data errors that may have been present, but unnoticed, for some time. For example, when maps of adjacent land parcels are overlaid by a computer for the first time, discrepancies in common boundaries may be noticed. The initial response to the discovery of such errors may be a costly attempt to improve the accuracy of the data. Some questions that should be asked first are:

-- Are the data accurate enough?
-- In the absence of a GIS, would the data be accurate enough?
-- What costs might be incurred because of inaccurate data?
-- Are inaccurate data better than none?
-- What is the marginal cost of improving accuracy/precision?

In the above example, boundary line errors could be corrected by conducting a new land survey or redrafting the maps to a common base, solutions that are both costly.

4. How important is accuracy compared to consistency and appearance? In order to accurately reference a map of a tract of land to known ground coordinates, the shape, orientation, or total area of the tract as mapped may change. A user may be forced to choose between keeping the appearance and acreage of a tract map consistent with legal records, or adjusting the map to gain locational accuracy.

5. Should more time be taken to build a database that can be accessed efficiently, or should the database be completed more quickly at the expense of subsequent data analysis? Because of technical considerations regarding file formats and database structures, shortcuts taken during database development can lead to difficulty in the later access of that data. Conversely, digitization procedures that may seem tedious and time-consuming can enhance the efficiency of later processing steps.

6. What is the desired spatial resolution of the database? For example, in a map of water bodies, one may have many small map units representing small streams, or fewer large map units representing larger rivers. The choice of map unit size will influence the size of the resultant computerized database as well as its variability, accuracy, and precision. The size of the minimum mapping unit should reflect the eventual use of the data. Generally, higher level managers are satisfied with information in a broader, more general form; lower level managers may require more detailed fine-resolution data.

7. Is the data base anticipated to be static, or are additions and deletions anticipated? The answer to this question will have a significant impact on the development of file-naming conventions and coding schemes used to represent attributes associated with maps. It is important to devise a coding system that provides enough flexibility to accommodate changes while meeting the constraints of a particular GIS. For example, assigning code numbers or names to map features when digitizing will have a significant impact on the ease with which items may be later retrieved from the database. Questions regarding coding systems will arise during pilot projects and are

best resolved through consultation with vendors and other organizations experienced with the same GIS.

8. <u>How should the digitizing effort be prioritized</u>? Three general approaches should be considered. The first is the application-oriented approach, which involves digitizing data as specific analysis needs arise. In this way, a database is built in pieces in response to certain projects or problems. A second approach is to build a comprehensive database for the entire area to be managed, proceeding by geographic or administrative areas. This is especially useful when an organization has an administrative hierarchy that reflects geographic regions. This approach provides a useful set of data for each region in turn, allowing regional users to begin to use the GIS one at a time. The third approach is to build the comprehensive database by categories. For example, transportation routes could be digitized for an entire region, then soils information, political boundaries, hydrology, etc., added in sequence. Using this approach, numerous users get access to a portion of the database at the same time.

DETERMINING YOUR GIS REQUIREMENTS:
The Critical First Step

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ABSTRACT

The most important decisions organizations will make when developing a geographic information system are those decisions regarding what information should be available and how the information will be presented. Understanding the real organizational needs is essential in order for the system to meet the expectations of managers, users, contractors and systems analysts. Specific requirements, agreed upon in advance, can save an enormous amount of time and money during development and long after system installation.

This paper presents a seven step checklist for developing a useful requirements document:

* Get the right people involved
* Determine the scope of the project
* Understand how you function TODAY
* Critically evaluate the existing information system's shortcomings
* Identify constraints - both internal and external
* Document the objectives of the new system
* Develop a description of the proposed system

1. INTRODUCTION

Once you're convinced that your organization needs a geoprocessing system, how do you decide what your specific GIS requirements are? Any new information system demands a critical look at three critical issues, regardless of whether the existing system is manual or partially or fully automated:

1. How do you do business?
2. What you need to do business in the future?
3. How you can do business better?

A geoprocessing system that will meet the requirements of an entire organization requires a structured approach to answering these questions. Done comprehensively it can save money and make the installation go more smoothly. Done haphazardly or quickly, it can substantially increase the cost of the system -- and significantly decrease the value.

A major rationale for investing in a GIS is the recognition that the existing geographic records system is not meeting the needs of the organization. However, in order to ensure a successful transition to a new system it is imperative to remove any semblence of individual guilt or responsibility for the shortcomings of the existing system. Frequently, a consultant can aid in the process of defining the new system while minimizing the "finger pointing" that can happen during the evaluation.

Also, recognize that **the new system will provide for (and indeed must allow) activities that you don't do today** -- either because the information doesn't exist or because it would be too costly to do the activity with your current system. The implementation of a GIS is often the first major opportunity to completely revamp the record keeping and reporting systems of the organization. Many of the applications that you will be doing in ten years, users simply cannot envision today. We have found that the list of applications that people start with usually amounts to less than 10% of the eventual applications that are installed to meet the growing needs of the organization. For this reason, the GIS must be flexible enough to expand over the next twenty or thirty years to meet these unknown application needs.

The outcome of the requirements analysis is a Requirements Statement. It describes the current system in functional terms. (Functional refers to responsibility areas like engineering, planning, operations, construction, assessment and mapping and records.) It assesses information requirements for each functional area. Those requirements are then evaluated in light of both internal and external constraints.

Most importantly, the Requirements Statement serves as a "controller of change." It guides the development staff and gives users a clear idea of what the new system will accomplish. It is the blueprint for the database design, determining which facilities will be managed (e.g. parcels, streets, water mains) as well as what information will be available for each of those facilities (e.g. year installed, property owner name or mailing address, lot identification number, or type of water or sewer service).

The Requirements Statement should also include a general description of the applications to be developed and the data that will be required for each. These should be described in sufficient detail to determine where interfaces to existing databases or systems are required, as well as the specifications for reports and other output documents.

2. STEP ONE: GETTING THE PROJECT TOGETHER

Choosing the right people for your GIS project is no small task. Organizing the project team and getting executive sponsorship and representation from users can consume a great deal of effort. However, given the size of the investment in installing a GIS system this up-front time is time well spent.

The GIS Project team should include several levels of management, from both Information Systems and user departments. Information Systems provides valuable input on how the GIS can be integrated with existing data processing operations and systems. User departments are the ones most affected by the installation of GIS. They are the ones who can and should define what the system will do for them and how. No project can be a success without the participation of both groups.

The project organization should include the following:

1. An **Executive Sponsor** - drawn from top level management of either a sponsoring user department or from Information Services;

2. A **Commissioning Body** - comprised of managers or directors from all user departments involved as well as Information Services;

3. A **Steering Body** - with representation of all user departments at the department head level and the Information Services department head who is supplying analyst and programming assistance;

4. A **Project Director** - from the user community, with some technical knowledge of GIS or the ability to learn it;

5. **User Representatives** - representing each area within the organization that will use the GIS;

By combining the expertise of all of these organizations, the GIS can be developed and implemented such that it fits the entire organization, not just one department or user.

Beginning at the top of the organization, you must select an "executive sponsor", otherwise known as a product champion. This individual should provide project visibility at top levels of management. He or she should ideally be an elected official, city manager, department director, or vice president, committed to the GIS project, and enjoy respect and rapport with the managers involved in the project. The executive sponsor must be available throughout the early development of the GIS, and well into the conversion of data and implementation plan.

How do you find the right person? Here are a few characteristics to look for.

1. Access to top decisionmakers - Often this sponsor is an officer or an elected official. Respect and credibility among peers are very important attributes for the sponsor. The executive should also be part of the "establishment". Having these attributes (respect, credibility, and existing access) make the process of educating other top management

easier and can "grease the skids" of the yearly budget battles that must be fought.

2. Understanding of the problem - From the user perspective, this is a critical characteristic. The executive sponsor must be in touch with the day-to-day operations of the organization in enough detail to understand what the current problems are and how they have arisen.

3. Genuine commitment to a solution - Look for an individual who is action-oriented and is committed to solving the problems of the existing system. This commitment must be sincere (and even emotional at times) in order for the excitement to "rub off".

4. Understanding of (or willingness to learn) the technical options available. Geoprocessing is complex and many solutions, not all of which are appropriate for each organization, are available. The executive sponsor must have the willingness and capability to understand the general assets and liabilities of each option presented. Why? Because the "best" solution may not be technically feasible or cost-effective. The executive sponsor must support the project team's decisions in upper management's eyes, and to do this requires some technical expertise.

One final rule about the executive sponsor. If you <u>don't</u> have one, <u>don't</u> do the GIS project.

Next in order is the commissioning body, the second level of management involvement in a GIS. This is a group of top managers (usually Vice President or Director level from Information Systems and user areas) who provide the project with top management visibility as well as direction at a policy level. It is the commissioning body's responsibility to maintain the project scope concerning what areas of the organization are to be addressed; determine which criteria will be used to evaluate the economics of the project; and to marshal the support within their departments to get the project staffed and underway.

Next is the steering body, made up of managers from user areas (generally at the department head level) and information services. It takes a more active role in the progress of the project. This

steering body would meet monthly, providing management direction for the project staff. This group reviews priorities on applications and implementation strategies and provides first line management review of the GIS project.

Next comes the project director, who is responsible for the day-to-day operations of the project. It is at this level that employees must be assigned full-time to the GIS project. Organizationally, the systems analysts and technical consultants should be under the direct control of either the project director or a member of the project staff, not "on loan" from information services. This position should be assigned a level of department head in most organizations. This gives the project director immediate budget and personnel control and allows he or she to maintain a cohesive project unit.

The last, and maybe the most important, group to be considered part of the project team are the user representatives. Each representative is responsible for one or more functional areas: design, planning, assessment, elections, construction, utility operations, right-of-way, mapping and records, field services, engineering. It is each person's responsibility to define data and applications requirements for the GIS; to evaluate the system as it is developed; and to prepare their peers for implementation. Carefully chosen for their knowledge, experience and peer respect, these representatives can make or break the project. Depending upon the scope of the project and the areas represented, a user representative may spend up to 75% of his/her time working with the project team to define the system requirements. Management and the project team must emphasize the importance of this involvement. Without it, it will be difficult to sustain the commitment of the user representative, their immediate supervisors and their peers.

3. STEP TWO: SCOPE OUT THE PROJECT

Determining the scope of your GIS Project can be difficult. At all levels of involvement the benefits of meeting all needs must be balanced with the practicality of managing the project. A clearly, concisely written statement of work can aid in assessing the importance of each requirement. It acts as a "guard-rail" defining the boundaries of the project and guiding it from start to finish.

Each organization is different. Though you may want to eventually solve all of the problems you have with geographically related records, you may not be able to address all of them at the same time. The scope of work defines which ones will be addressed as a "core system" and leaves others explicitly for continuing development.

Several issues should be examined in defining the scope of the GIS for the organization.

1. **Resources** - What resources are available for the GIS, including manpower and money? How much discretion does management have in reappropriating resources from other projects?

2. **Priorities** - What are the priorities of management and the goals of the enterprise? Can the GIS address the top priorities of the organization, and if so, what does that mean in terms of implementation priorities for the project?

3. **Politics** - Who will be the executive sponsor? Are there political realities that should be considered in assigning persons to the project or in allocating money? Are all of these political considerations internal to the organization or are there other factors (governing boards, state review committees) which should be taken into account?

4. **Philosophy** - What is management's philosophy concerning projects and economic justification? Can we take those into account in positioning the scope statement?

5. **Expectations** - What are the expectations of users and managers? Are they realistic? Is the perception of those expectations accurate? Can an education program be instituted to bring expectations in line with what the project team feels is appropriate?

6. **Technology** - Is the technology available to do what we want to do? What does it cost? Is the cost worth the value that we can obtain? Are there developments on the horizon that can asist in assigning priorities to the development of applications for GIS?

After answering all of these questions, typical projects publish a list of core system applications that includes mapping and design, some type of network analysis, and a selected few applications which have high visibility and high payback. These selected applications

are usually driven by the corporate sponsor and the steering committee's priorities.

4. STEP THREE: HOW DO YOU FUNCTION TODAY?

A thorough requirements study requires the use of a structured analysis methodology. It helps users and analysts to look at existing operations and to think about operations in functional terms. IIS has used a methodology called STRADIS, provided by McAuto Inc.

STRADIS (STRuctured Analysis, Design and Implementation of Information Systems) provides an organized set of procedures and guidelines for developing and maintaining information systems. These procedures and guidelines include standard "roles", activities, and techniques and guidelines that can be useful in developing any information system, including a GIS. The structured methodology also provides managers with a consistent set of tools with which to evaluate and compare projects, ensuring that priorities are properly placed.

One of the first major tasks in the structured analysis is answering questions and gaining an understanding of existing operations. This may sound easy for a project team made up of people who already work within the organization, but in practice, reaching a consensus regarding how an organization operates is difficult.

The first question is **who uses the information?** In developing the GIS, this group includes anyone who receives existing maps plus anyone who receives a report generated using map-related information. This can be a sizeable group of employees. In our experience this is never less than half of the employees of the entire organization.

Second, **what information is used?** (Not "what maps or reports are used?") The answer to this question affects what information is stored in your database, how that data is related, and what the maps and reports will look like. By determining the exact information that is gleaned from the existing source document, you can narrow down the choices for what that source can be in the GIS. It can also help users and analysts to look beyond existing maps and records, existing departments, or existing ways of doing business.

Third, **how does the information flows?** Define who generates it and how and where the information goes. Information flows among departments, individuals, databases, and job functions. The information flows should be defined in terms of functions (e.g. planning, engineering, emergency response, billing, customer service), and should include details about the source of the data, the form of the transmittal and the last function to receive the information.

Fourth, **what does the recipient do with the information?** Does he or she really use it? Do they create a report? Do they attach it to another document? Do they store it in a data base? If so, which one and what is the format? Do they dump it in a drawer and forget it?

Fifth, **what do each of the existing sources of information (computerized or manual) look like?** As you begin to collect the various sources of information, redundancy is the first thing that should become apparent. It is also extremely important that the project team and the user representatives be using the same terminology when referring to documents and data sources. Often different departments have different terms for the same source document.

Sixth, and finally, **how often is the information generated and/or needed, and how much (i.e., volume) information is involved?** The answers to these questions will give the system designers some very clear directions as to where and how data can be stored and accessed.

5. STEP FOUR: DEFINE THE PROBLEM - THE REAL PROBLEM

Where could things be done better? What functions can be affected by improving the availability of information? Where are the benefits and how much are they worth?

Identifying the real problem is often a difficult thing to do. One of our utility customers found that the information on existing maps was out-of-date and inaccurate. They thought that they had a mapping

and records problem. By analyzing the problem through a structured methodology, we found that the inaccurate maps were an effect. The cause was a work order system that did not provide for feedback or easy update to reflect field changes. Work orders came back from the field with absolutely no changes. Even the designers knew that changes were made during construction, but there was no mechanism in place to record the changes and to send them back to the designer or the records office.

To solve the problem, the customer instituted a system that provided for daily update of work orders by the construction crew foreman. These are signed by the foreman and are the responsibility of the individual construction crew.

The moral of the story is "Do not attempt to solve the problem by analyzing or treating the symptoms". Even the best designed information system cannot correct underlying procedural problems that may exist.

6. STEP FIVE: IDENTIFY THE CONSTRAINTS

Many constraints will come to light as you begin to analyze the GIS installation and attempt to manage the scope of the project. There are a few which cannot be overlooked.

Legal requirements cannot be overlooked. For a gas utility, many user requirements are legal requirements. For example, gas companies must be able to tell any agency within 24 inches where an existing facility is. Most companies solve this problem through providing the dimension of all facilities on maps and output documents, a critical requirements in designing new map output for a GIS that is shared by other agencies.

In many counties, state statutes very rigidly define how property will be appraised (including what the criteria shall be in determining property value, e.g. soil use, structures, etc.) and how map documents will look (scale, annotation, and the like).

Compatibility with the existing environment (i.e. customer information, assessment and billing, material management, and construction scheduling systems) should be a requirement, but it is often overlooked. Part of the systems analyst's job is to educate the user about the importance of these ties and the capabilities of the GIS to address other non-mapping areas of the organization.

Should the system be **centralized or distributed?** This can be a question of practicality and of organizational constraints and operations. Issues like backup and recovery, communication, size of the territory, availability of personnel all come into play in this decision. If a decentralized system is installed, technical support may be required at each installation. If users at a central site require system-wide information, special system software may have to be developed. If all data is centrally located, high speed communication lines will be required to meet remote location demands for information.

When does the system have to be available? The system response time requirements and hours of operation of a police department GIS are not the same as a utility GIS. These varied requirements have a major affect on hardware and software decisions, especially if needs of both types of operations must be met by the same system.

Budgeting constraints can be critical. The project schedule and scope may be dictated by this one constraint. Financing opportunities should be reviewed as well as the overall ability of the organization to support the defined scope of the GIS. No single department should bear the total cost of a GIS that is shared among the various departments in the organization, though often one "lead department" should be designated as the coordinating agency.

7. STEP SIX: WHAT ARE YOUR OBJECTIVES?

Business objectives outline what you want to accomplish. For example, a business objective may be stated this way: "Create assessor maps and records that meet state requirements". The business objective must be specific enough to be compatible with the project scope and general enough to accommodate all possible solutions.

The next step in defining your objectives is defining **"enabling tasks"**. These tasks list what's required to reach the business objective, who needs to be involved, and what studies will be accomplished and when. Typical enabling tasks are: "assign user representatives", "conduct interviews", and "document user requirements".

Finally, **system objectives** are specific statements about what the information system must be able to do. For example: "The GIS system must satisfy the long-term geographic information requirements of users and provide needed information in a manner that enhances their productivity."

8. STEP SEVEN: DESCRIBE THE PROPOSED SYSTEM

The proposed system should be described in enough detail to allow the user to see what information will be available and in what form. For example, if the product is a map, the description should include a list of information to be shown on the map (facilities or geographic entities), the scale, how it will be accessed, who the principal users are, and any constraints or limitations imposed by the system. A sample should be provided if at all possible. Also, be sure to identify where the data will be stored and how it will be accessed.

If the product is an on-line inquiry system, the proposed system description should provide details about access, sample input screens, and sample output.

9. THE DELIVERABLE: THE REQUIREMENTS DOCUMENT

The end result, after up to a year of analysis, is the requirements document. It will serve many purposes as the implementation of a GIS continues.

First, it is a published statement of work, a contract between the user and the developer and plan for implementation. It gives users and information systems personnel a common ground from which to

discuss and develop all of the products that are required for full implementation of the GIS. The details of deliverables have been outlined and agreed upon in advance of development. In fact, in many cases, the user representatives may sign the document along with the members of the project team and the steering body.

The requirements document should also serve as the basis for an RFP for the actual system. The system choice, including hardware and software, should be driven by the requirements, not the other way around.

The requirements document also guides and controls change. It alerts everyone to the major changes that they can expect, not only in where they get their information, but also in the basic job descriptions that will change with the GIS.

10. CONCLUSION

You would not build a house or a factory or a hospital without a blueprint, nor would you contact a contractor to build it without working drawings. The requirements document is the blueprint and working drawings for your GIS system and should be used as such. It should provide an undisputable statement of work for an agreed upon schedule and price, while allowing for a structured change procedure as new information comes to light or as the priorities within the organization change.

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DERIVING VALUE FROM THE MODELLING AND ANALYSIS OF SPATIAL DATA

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ABSTRACT

During the past few years, it has become widely recognized that geographic information users have demonstrated a noticeable change in their system requirements.

In the early stages of the development of Geographic Information Systems, the users who were primarily custodians of large paper data bases were concerned with the capture, conversion and organization of geographic data. The principal value of GIS to these individuals was the ability to reproduce, modify and retrieve geographic information more effectively. The resources available for achieving these objectives was significant.

As digital geographic data bases become increasingly accessible, a new crop of GIS user is emerging who has a different set of needs and resources. The first of these individuals are seeking GIS capabilities that permit the analysis of spatial data. For them, value is the ability to compare, juxtapose and cross-reference different sources and layers of spatial data to create new information of knowledge which was previously difficult to infer of verify.

Another, but closely following, progression of requirements amongst these users is the emerging demand for spatial modelling. While not yet well defined and understood in this stage, the user builds on the knowledge and information produced by analysis to predict outcomes on the basis of hypothesis or derived relationships.

DERIVING VALUE FROM ANALYSIS AND MODELLING OF SPATIAL DATA

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1. INTRODUCTION

The role of a Geographic Information System (GIS) is shifting from that of a computerized custodian concerned with data capture, conversion and organization to a decision-making tool. Simply querying a dataset or graphically displaying an attribute, a major achievement in the past, is no longer sufficient.

There is now emerging a demand for analyzing and modelling spatial data to build knowledge and predict outcomes on the basis of hypothesis or derived relationships. Now more complex analysis functions and the integration of data from different sources allows GIS users to attempt to explain relationships, develop policies or simulate impacts or changes.

While many GIS users intuitively recognize that the analysis and modelling of spatial data can create value, the concept of what constitutes value is not really well understood.

The task of understanding value is made more difficult by the emergence of increasingly complex (and long) lists of user requirements which have to be matched with equally complex (and long) sets of GIS manufacturers' specifications.

For those of us involved in the development, marketing and consulting of GIS products and services, it is important to have some straight-forward concepts for classifying value. The purpose of this paper is to attempt to develop a structure for understanding aspects of value which seem to be associated with the analysis and modelling of spatial data using GIS. A typology for describing types of value is presented and applied to several real user situations to test its appropriateness.

2. DEFINITION OF THE CENTRAL CONCEPTS

To explore the idea of value in spatial analysis and modelling, it is necessary to establish clear definitions of some of the central concepts. Words such as data, information, knowledge, model and value need to be explained. There are definite distinctions between the terms data, information and knowledge. (Bedford and Onsi, 1969)

Data can be considered a collection of direct observations arranged in an orderly way to represent facts.

Information represents data organized for a specific use and can be considered the fundamental material upon which intelligent action is based.

Knowledge can be referred to as the evaluation of data or the accumulation of information for general use in the future.

A Model can be a theory, a law, a hypothesis or a structured idea; it can be a relation or an equation; it can include reasoning about the real world by means of translations in space (spatial models) or in time (temporal). In this paper the word model is used as a noun implying representation. A spatial model allows for visual comprehension of otherwise complex phenomena. It can describe the framework wherein other information can be defined, collected or ordered. Spatial modelling allows the maximum amount of information to be squeezed out of the available data by structuring it geographically. (Chorely and Haggett, 1964.)

The definition of Value has been tackled by a wide range of disciplines, from economists, appraisers, accountants and philosophers. The results of all of these efforts show that value cannot always be calculated with mathematical precision. It seems that the concept of derived value has to be measured or sensed by the receivers in terms of its use to them.

User needs are often defined in terms of their generic discipline, i.e. forester, geologist or market researcher. Our experience, however, suggests that individual users within a discipline can exhibit significantly different "values"

because of the type of needs. When analysis and modelling is being used, we have found that there appear to be three types of requirements which can help in describing an end user.

<u>Case 1:</u> The user wishes to perform operations that are aleady being done, either manually or by another method.

<u>Case 2:</u> The user wishes to perform operations that are theoretically well defined, but for one reason or another cannot be executed.

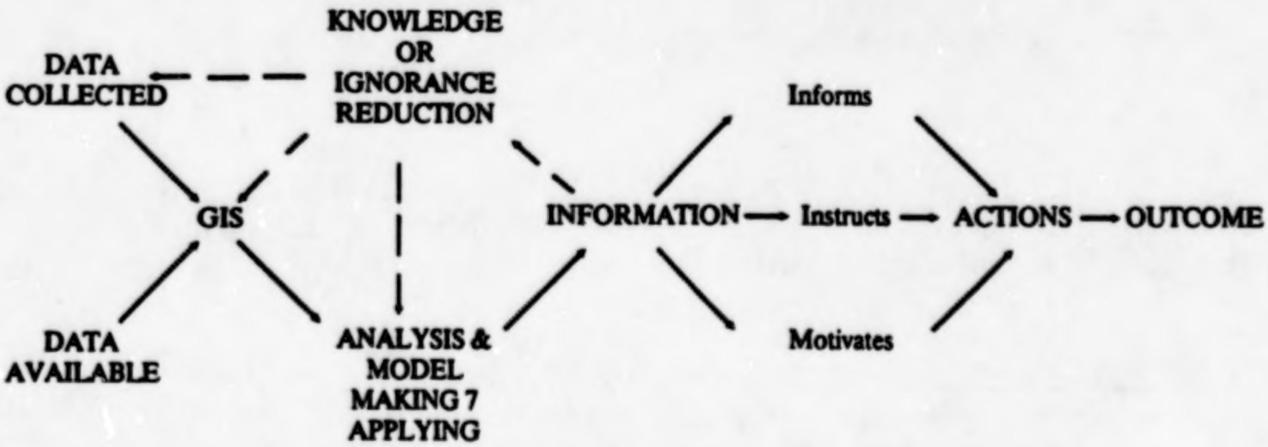
<u>Case 3:</u> The user wishes to develop, test and validate new theories or models in specific fields, general areas or disciplines of interest.

Assuming that this somewhat general definition of user needs is adequate, we will attempt to define an appropriate way of measuring generic types of user value.

<u>Value due to Efficiency:</u> In the GIS field there are several levels at which value can be calculated. All of these are related to the hypothesis that value is derived through the conversion and transformation of data into information and knowledge. Exhibit 1 shows a schematic diagram of the conversion and transformation process.

Available data, or data specifically collected by the user, are entered into the GIS system. The user, with some prior knowledge, is able to assess the analytical capabilities of the GIS to process the data and convert it into information, either through analysis, model making, or by assessing an existing model. As a result of this information our knowledge or as some have described it (Bedford and Onsi, 1969), our ignorance, is reduced. Through this process we may change our perceptions of what data we should collect, what GIS functions we require, or how we may analyze, make or apply models. The first type of value, then, is the value resulting from the ability of the GIS to efficiently convert data into information. Once data is turned into information it can produce value.

EXHIBIT 1 - TYPES OF USER VALUE



1. Value resulting from the efficiency of converting data into information using GIS.

2. Value resulting from acctions ccaused by information produced by GIS. oduced by GIS.

3. Personal (intangible) value associated with adoption of GIS.

Value due to Action: Bedford and Onsi (1969) have suggested that the value of information can be measured by comparing the outcome of actions of the decision maker before and after the receipt of the information. They have proposed three ways in which information can change actions:

-- by "informing" the decision maker and thereby altering the probable choice of course of action;

-- by "instructing" the decision maker in making basic choices from among potential courses of action, and

-- by "motivating" through the change in value of the outcome of a course of action.

Actions resulting from this information causes outcomes which may be different from what would have occurred if the information had not been available. This differential of outcomes can be used to assign value (assuming that it is positive).

Value due to Personal Intangibles: Thus far, all of the measures of value which we have defined are potentially measurable. It is clear, however, that in any professional endeavour there is a plethora of factors which are difficult to express quantitatively but are nonetheless important in influencing the perception of the professional.

Value can be assessed at a personal or intangible level. There will always be a rivalry between those things which catch our interest and those things which are practical and accepted to do. It is impossible for even the most gifted to totally exclude the personal component of value from his judgment (Ravetz 1971). Ravetz has rightly documented that "the most effective advancement of the field requires more than a single isolated worker and winning support requires propaganda, both to explain the work and to convince others of its value. To ignore the social aspects of the task while presenting one's results, or even when planning the strategy of a long campaign of investigation is, in effect, to abdicate responsibility from the work and to be concerned only with one's private pleasure".

3. ASSESSMENT OF PLAUSIBLE, VALUE AND NEED COMBINATIONS

If we now take our three types of user "value" and combine them with our previous definition of user "needs", we can construct a framework for assessing plausible matchings. Exhibit 2 assesses the validity of each possible user need and value combination.

The first type of user value is related to achieving efficiency in operation. It is apparent that this kind of value can only be gained in situations where the user is already performing the required analysis and modelling operations either manually or by another method. Cost benefit approaches can be used to calculate the potential value of the GIS alternative.

The argument for value through efficiency cannot, however, be attributed or calculated in instances where the user's need is not currently being provided by other methods (Case 2 and Case 3).

Value resulting from outcomes due to actions can only be attributed and calculated for Case 1 and Case 2 needs. That is, where new information from GIS analysis and modelling will cause different and positive courses of action to be taken. If the user is already receiving the required information, either manually or by another method (Case 1), value due to action can only be assigned if the required information is produced by the GIS more quickly and there is some value to the timeliness of such information. For example with current methods we may be able to predict when earthquakes will occur in broad geographic areas. However, these methods may only be able to produce reliable forecasts minutes before the event. If, through GIS analysis and modelling, a user were to be able to reliably predict these events hours, or days, in advance with more precision, great value could be assigned to this capability.

Value cannot be attributed due to action in situations where the information that is produced is yet unknown. Thus, in a pure research activity (Case 3), actions resulting from information and knowledge produced by the research can only be calculated after the fact.

Personal intangible value can exist for each type of user need. Careful scrutiny of user intangible values can often result in their translation into either efficiency or action type values. The remaining types of value, claimed to be intangible, seems to relate to the user's relationship with his peer group. Thus, for example,

EXHIBIT 2: ASSESSMENT OF PLAUSIBLE USER NEED AND VALUE COMBINATIONS

	TYPE OF USER NEED		
	APPLICATIONS ORIENTED (Respond to a Need)		RESEARCH ORIENTED (Create a Need)
	CASE 1	CASE 2	CASE 3
TYPE OF USER VALUE	Perform operations already being done either manually or by another method.	Perform operations that are theoretically well defined but cannot be done by other methods.	Develop, test and validate theories or models not yet defined.
Due to efficiency	Can be attributed and calculated using before and after cost benefit approach (or method).	Cannot be attributed or calculated since there is no base for comparison with before case.	Cannot be attributed or calculated since there is no base for comparison before case.
Due to action	Can only be attributed and calculated if the operations can be performed more quickly and timeliness affects the value of action.	Can be attributed and calculated using before and after cost benefit approach (on actions).	Cannot be attributed or calculated till after the research is completed.
Due to personal Intangibles.	Can be attributed but not calculated. Often related to whether peers are making the same choice.	Can be attributed but not calculated. Often related to the desire to be the first to implement a new approach.	Can be attributed but not calculated. Often related to a judgement that type of research to be carried out can be helped.

the user may place value on adopting GIS analysis and modelling techniques (in a situation where he is conducting well-defined operations Case 1) because he may feel that this step brings him closer to the state-of-the-art of his peer group.

Similarly, a user who is using analysis and modelling capabilities of a GIS to implement operations that are understood but which have not yet been completed (Case 2), may place greater value on being a leader among his peer group.

And lastly, an individual involved in pure research in a particular field, may put greater value in discovering new knowledge and developing theories which are the basis of new paradigms for the peer group.

The somewhat complex matrix of Exhibit 2 can be turned to a more simple schematic (Exhibit 3) to show a pyramid of types of values resulting from analysis and modelling with GIS. This pyramid is crowned at the top by the measure of value related to reduced effort required to perform existing well-defined technological and modelling tasks.

The middle layer of value is also measurable and is related to the GIS capability to either produce more timely existing information or new information which will result in actions and outcomes that have benefit to the user or society.

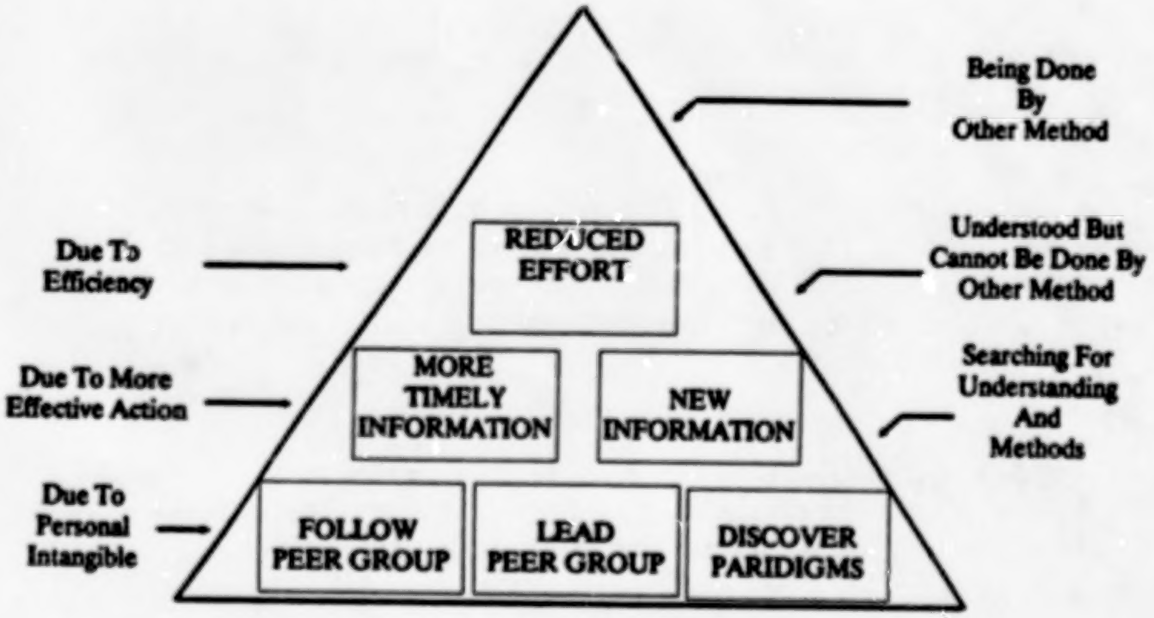
The base of the pyramid consists of the personal and intangible values which cannot be measured, ranging from the desire to follow or lead one's peer group, or to discover new paradigms.

While any generalization of such a complex set of issues will be deficient, we have found that this simplified representation can be used to successfully classify user needs.

4. CASE STUDIES OF DERIVING VALUE FROM ANALYSIS AND MODELLING

To illustrate the validity of derived typology of value, three very different case studies are presented. These case studies are drawn from the client experience of TYDAC Technologies.

EXHIBIT 3 - ANALYSIS & MODELLING GIS USER VALUE PYRAMID



4.1 Case Study #1: Retail Store Trade Area and Related Analysis.

This first case study deals with a well defined problem in the market research field dealing with the geographic definition of trade areas and other store performance measures. The user group was made up of researchers in a private corporation who were responsible for conducting trade area and related studies. Prior to this time such studies were carried out through a semi- automated process using spreadsheets and database management systems. While geography was an important dimension of the analysis, no formal GIS was being used.

A pilot retail/market study was developed to demonstrate the ability of a GIS to duplicate the procedure followed by the market-reseachers in defining trade areas. These trade areas were based on store location, location of competitors and population. The purpose of such an analysis was based on the need to monitor store performance, to justify upgrading an existing store, to warrant the building of a new store, or the closing of an unprofitable store. (TYDAC, 1987)

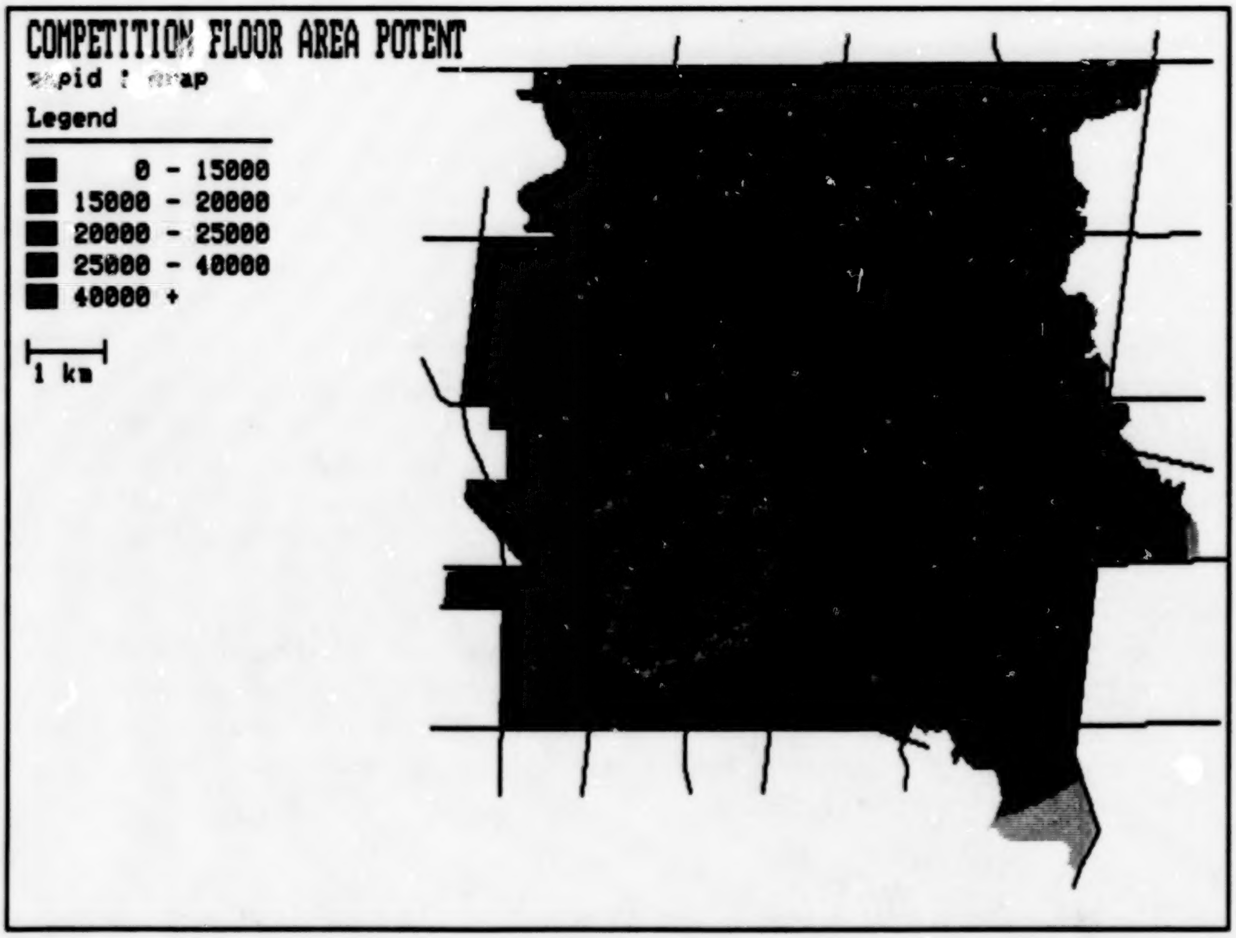
Much of the marketing/retail data was collected by a fixed reporting unit, often the census tract. Attributes such as income, population, and family size were useful in this type of analysis. Additional information from in-house store surveys described the general shopping behaviour and the socio-economic characteristics of those interested.

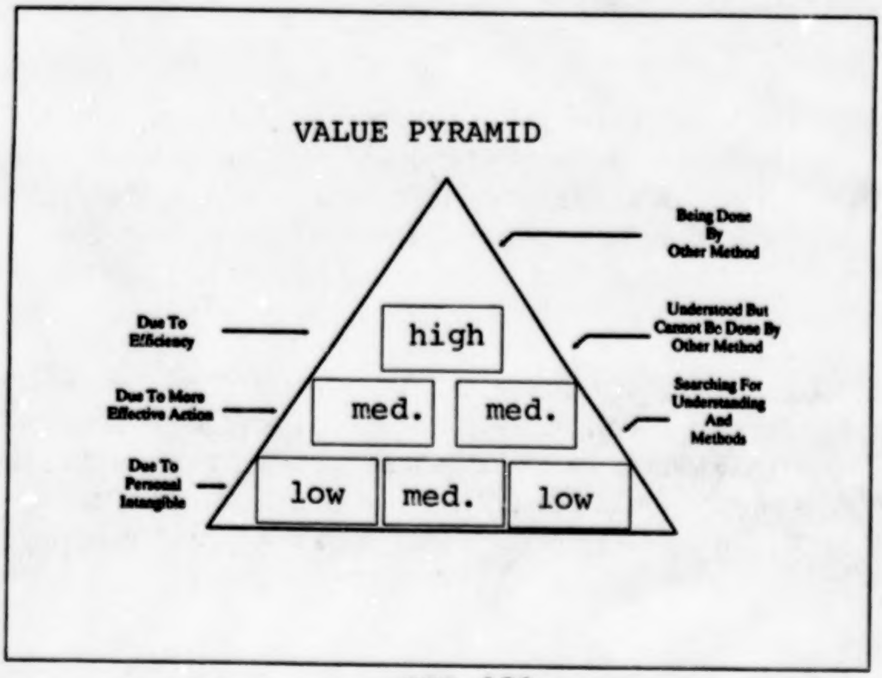
The use of the analysis and modelling features of our GIS resulted in value to the researchers in several ways. Using the framework which we have established in the previous section, this consisted of:

Reduced effort (high value) The ability to reproduce the manual and semi-automated procedures previously employed to define trade areas with less effort (person days) was of significant value to the researchers. Many store studies are carried out during the course of a year and the ability to either reduce costs or improve the quality of data collection and analysis had high value.

More Timely Information (medium value) The presentation of intermediate data and analysis results in a mapped format (which was easier to visually comprehend) and was seen as the major benefit. The researchers stated that the visual display of information in a mapped format creates a more effective communication to a wider range of decision makers involved in managing the retail store.

EXHIBIT 4: Case Study 1. Market Research





New Information (medium value) The availability of the GIS enabled the researchers not only to replicate their present method of analysis but also to explore new ways in which trade areas might be defined. Using a distance decay smoothing function (potential mapping) of the GIS package, the researchers were able to integrate the distribution of survey respondents and the relative accessibility of respondents to competing stores to identify the geographic areas of above- and below- average store performance.

Follow the Peer Group (low value) The adoption of the GIS was not strongly motivated by a desire to follow the direction of the peer group. It was recognized, however, that increasingly, GIS methods are being applied to their market research endeavours.

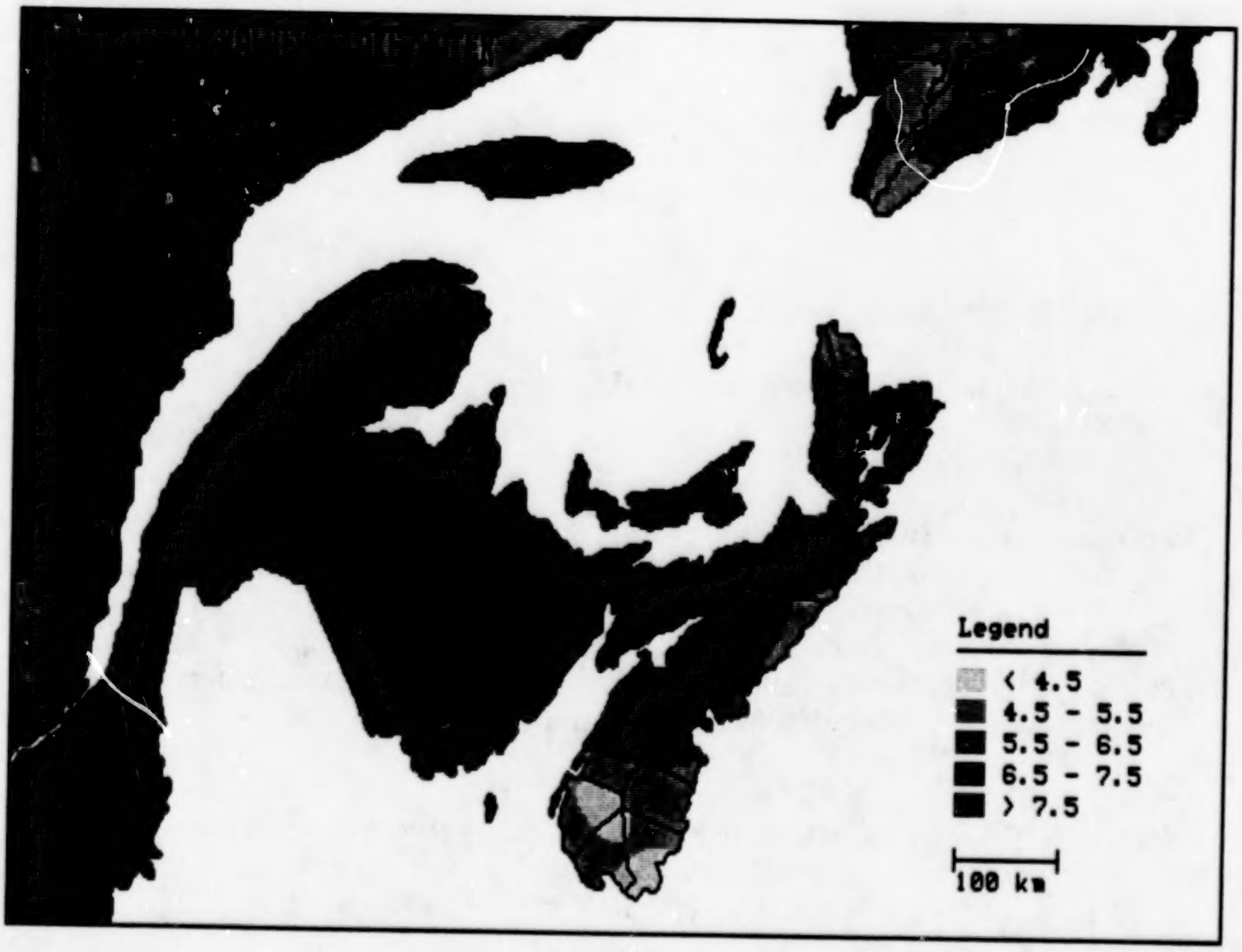
Lead Peer Group (medium value) During the course of the pilot study this aspect of value gained more importance in the minds of the researchers. It was stimulated by the experience of using the GIS technology for analysis and modelling. Since the researchers were employed in a private company, the essence of this perceived value was in relation to other market researchers within their own organization rather than with outsiders.

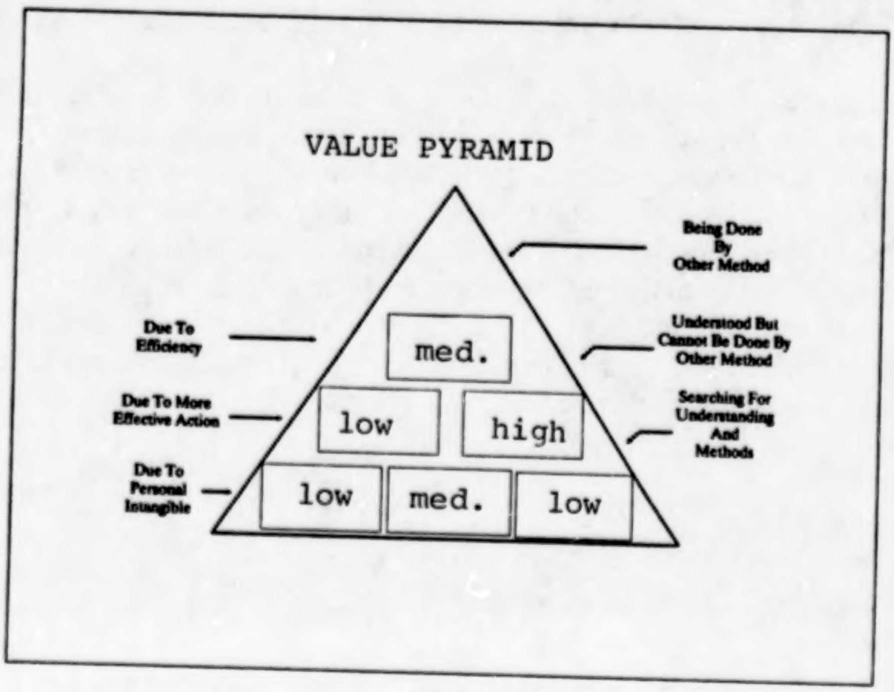
Identify a New Paradigm (low value) Since the market research group was primarily applications oriented there was a relatively low value placed on the ability to use the GIS system to develop new theories and approaches.

4.2 Case Study #2: Economic Impact of Reductions in Acidic Emissions.

This second case study illustrates user values in a situation dealing with a major public policy issue. For some time there has been a spirited debate amongst scientists and environmental managers on the effects of acidic emissions on a variety of natural and man-made resources. In Canada there has been much concern about the effect of acidic emissions on aquatic life in lakes and streams, and in particular, on the native fish population which is the basis for a considerable sports fishing industry. In an attempt to influence more rapid adoption of emission reduction programs, various governments in Canada have funded research into the economic benefits to be derived from reductions of emissions.

EXHIBIT 5: Case Study 2. Acid Rain Impact





This case study was conducted by a consulting company. The study was commissioned to assess the local economic benefits (to the sports fishing industry) of reductions in emissions. An important aspect was a recognition that the biological and economic impacts of reduced emissions needed to be assessed at a fine geographic level. (Simmons and Bitterlich, 1986)

The study utilized available research and experience from a variety of countries (Norway, Eastern U.S. and Canada) as well as experimental data by fisheries experts on the effects of different acidity levels on the population, age structure, egg development and inhibition of spawning. The relationships between sulphate emissions and depositions were postulated and hypotheses were incorporated into the analysis to estimate changes in deposition resulting from changes in emissions.

Data on fishing experience and intensity were related to the presence of fish populations and through this series of links, the economic consequences of emission changes were calculated.

The consultants involved in this study exhibited the following set of values.

Reduced Effort (medium value) Since no study of this kind had been carried out before a medium value was placed on the ability to reproduce existing analysis and modelling operations more efficiently.

More Timely Information (low value) While there is a considerable urgency in dealing with the reduction of acidic emissions, the nature of the decision making process is a legal and political one. It is only moderately sensitive to the speed with which information is provided. Thus the investigators placed a relatively low rating on the ability to produce more timely information.

New Information (high value) Although the method for carrying out this impact study had been carefully planned and there was confidence that it could be executed (in theory), the work had not been done before. As a consequence, the user placed a high value on the ability of the GIS system to effectively translate the defined modelling approach into a workable process. Another aspect which emerged as important to the investigators was the ability to pinpoint, visually, the

location of highest potential benefit. This new information, it was felt, would stimulate decision makers into working more diligently to achieve emission reductions.

Follow Peer Group (low value) There was very low value placed on following the lead set by the peer group since the very nature of this investigation was to implement untried methods.

Lead Peer Group (medium value) The very nature of this investigation placed a reasonably high value on the ability to demonstrate the implementation of a sophisticated method for assessing the impacts of emission reductions. It should be observed that not all team members viewed this aspect with equal consideration. For example, the biologists tended to place a lower value on this aspect than did the economists.

Discover Paradigm (low value) This application was not primary research but to illustrate how existing knowledge could be coupled to reach sensible action. As a consequence, only a low value was placed on this aspect of the GIS.

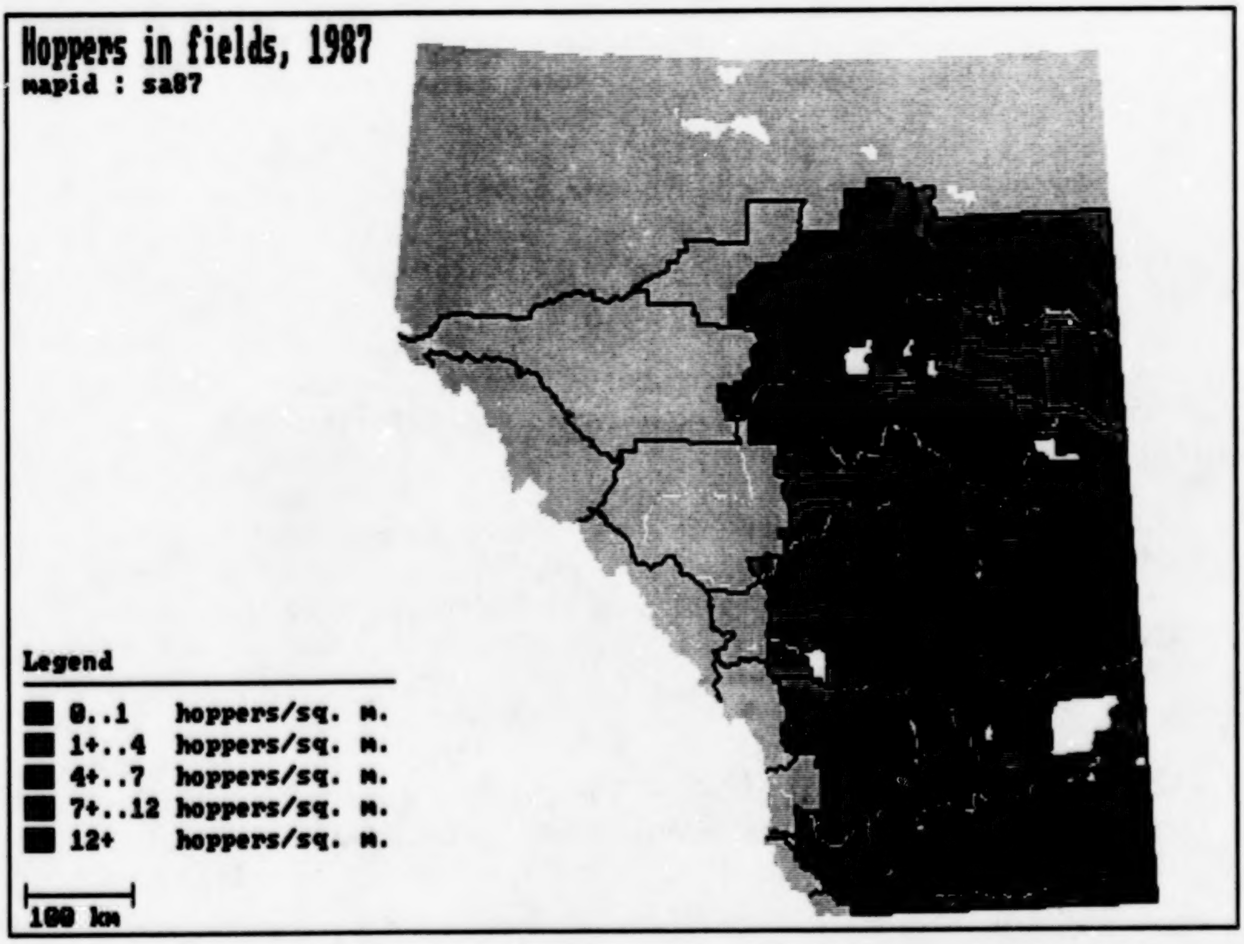
4.3 Case Study #3: Forecasting the Distribution of Grasshoppers.

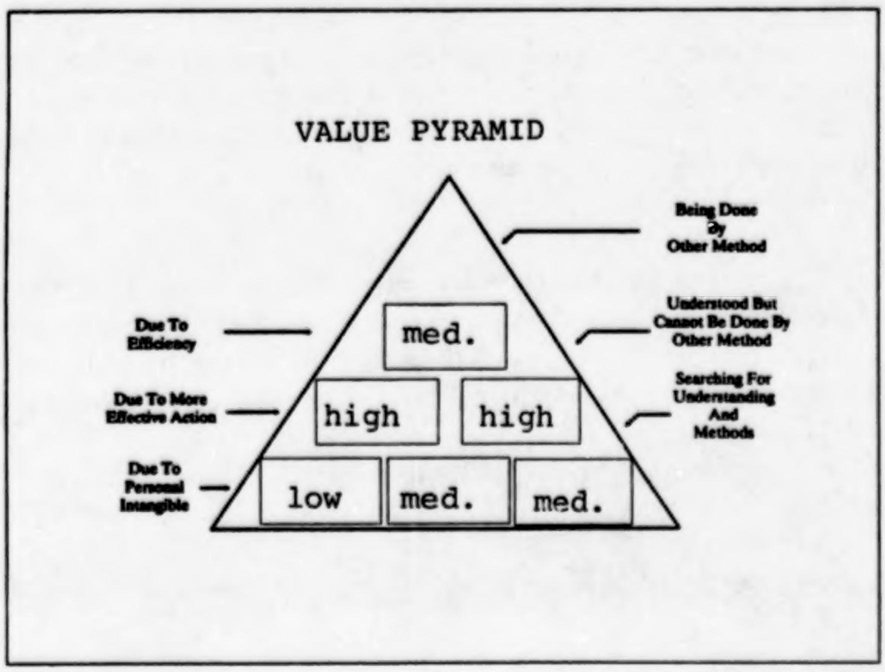
Grasshoppers are one of a number of pests which can cause substantial damage to agricultural produce. The prairie regions of Canada and the U.S.A. are particularly susceptible to the incidence and occurrence of grasshoppers. Agricultural scientists and entymologists devote considerable resources to monitoring the incidence of these pests to better assist farmers in the application of insecticides. Understanding the process of the diffusion of grasshoppers from year to year can provide valuable insight which can help agricultural agencies and farmers plan for their control.

This case study illustrates the type of values which are considered important to agricultural research scientists responsible for a grasshopper monitoring program.

The process of understanding grasshopper outbreaks is predicated on the assumption that these large scale spatial dynamics are affected by local conditions. Previous research had indicated that distribution and density of grasshoppers showed a positive correlation to heat accumulation and negative

EXHIBIT 6: Case Study 3. Grasshopper Forecasting





correlation to rainfall (MacCarthy, 1956; Edwards, 1960; Gage and Mukerji, 1977). Through the use of the GIS system the researcher was able to construct potential maps of rainfall and sunshine hours and successfuly correlate these with reasonable accuracy to grasshopper density maps over different years. The initial stages of this research have now been supplemented by further analysis and modelling work to improve predictive capabilities of the initial model by incorporating other geographic databases related to soils and geomorphological (Johnson and Worobec, 1987) classification. The potential for a more finely tuned temporal dimension to these models may also be explored.

As a result of observation and discussions with the principal researchers involved in this application, the following perceptions of value were identified.

Reduced Effort (medium value) The time consuming process of mapping field data and aggregating it by reporting unit to estimate future levels of grasshopper population by manual and semi-automated methods was significantly reduced by the adoption of the GIS approach. However, this was only a medium value to the researchers.

More Timely Information (high value) The ability to incorporate new field data and generate more timely situation analyses and forecasts had a high value to the researchers. By reducing this time lag more effective monitoring and remedial actions could be taken during the course of the infestation.

New Information (high value) The ability to produce new information by the adoption of different modelling/transformation procedures (potential mapping) was of high value to the researchers. Higher resolution patterns of distribution density of the pests enabled the researchers to gain both a technical and an "intuitive intimacy" with the field data which was not possible before.

Follow Peer Group (low value) The very nature of this research activity was to develop and enhance present methods for understanding the grasshopper defusion process. A very low value was therefore placed on the analytical and modelling features of the GIS which enabled the researcher to follow the practices of the peer group.

Lead Peer Group (medium value) There was a definite strong value placed by the researcher in using GIS analysis and modelling capabilities to operationalize already articulated theories.

Discover Paradigms (medium value) Given the exploratory nature of the research work a medium value was placed on the ability to have access to a tool with a broad range of analysis and modelling capabilities that are required in the process of searching for and developing new paradigms.

5. CONCLUSIONS

The case studies and other tests with different user situations has shown that the typology which has been defined seems capable of identifying subtle differences between the values of users.

In its present form the typology is only useful as a general tool for classifying users with similar value profiles.

It may be possible to extend the typology so that it is more comprehensive and can be tied into detailed user requirements and manufacturers' specifications, but more work will be required to develop compatible hierarchies within this broad framework.

The results of our work suggest that during the early stages of defining a user's needs, this structure can be helpful in formulating questions that are designed to expose the user's value pyramid. With this information the anaylyst, or software supplier, can more quickly focus on the salient features of a proposed GIS solution that will closely meet the user's requirements.

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LAND RESOURCES

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THE SALT RIVER PROJECT'S LAND USE MODEL: A MULTI-DIMENSIONAL TOOL FOR ALLOCATING FORECASTED LAND USE TYPES

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ABSTRACT

The Salt River Project Land Use Model (LUMOD) is based functional relationships of disaggregate land use data for thirty-three land use types, collected at a forty-acre level of spatial resolution. Using some of the theories of entropy maximization derived spatial allocation models and choice analysis, LUMOD allows land uses to simultaneously compete for the vacant, developable land available

An interactive graphics program incorporating image-processing type commands increases the analyst's interface with LUMOD and allows a wide range of applications: water resource management, environmental analysis, transportation development, facilities planning, power systems analysis and demand-side implementation.

1. INTRODUCTION

Metropolitan Phoenix is the fastest growing major metropolitan area in the United States, expanding nearly one and a half times faster than the national average (1). Ranked 24th in population in the country (2), the "Valley of the Sun's" growth is attributed to migration rather than natural increase (3), which makes the future landscape of Phoenix difficult to predict.

Originally concerned with forecasting the electrical power needs of the Valley, the Salt River Project (SRP) developed a land use model, LUMOD, to understand when agricultural and desert land would most likely be urbanized. LUMOD expresses functional relationships between land uses in the Phoenix metropolitan area, and produces forecast maps of ten major land uses on a disaggregate level using some of the theories of entropy maximization derived spatial allocation models and choice analysis.

The interactive environment of LUMOD accelerates the analyst's understanding of the forces of urban change and the relative importance of various development influencing factors. LUMOD allows the analyst to view and modify land use relationships, and within minutes, analyze the resulting forecast maps to reach an accurate prediction of future patterns of development.

The Salt River Project is a water and electric power utility serving the Phoenix metropolitan area. This paper describes the construction of the SRP's Land Use Model and how the versatility of LUMOD allows a wide range of applications involving water resource management, environmental analysis, transportation development, demand-side implementation and facilities planning.

The LUMOD forecast process (fig.1) can be divided into five tasks. First, base year land use data are coded into the computer from aerial photography. Second, the number of acres of each land use to be allocated is an input to the model controlling the amount of growth distributed within a forecast period. These 'regional control totals' are determined outside the model using population and employment forecasts.

Third, geographically distinguishable variables or factors which have a potential influence in land use development decisions are coded and organized into factor maps. Fourth, preference function maps, composites of several factor maps, quantify observable locational behavior, and are the basis for competition among the land use classes to occupy vacant, developable land. Fifth, the forecast routine allocates the forecasted regional control totals to vacant, developable parcels according to the relative magnitudes of the preference function maps. Each parcel containing vacant land is given an allocation of some combination of residential, commercial, industrial or vacant land use. The following sections offer more detail on each of the forecast tasks.

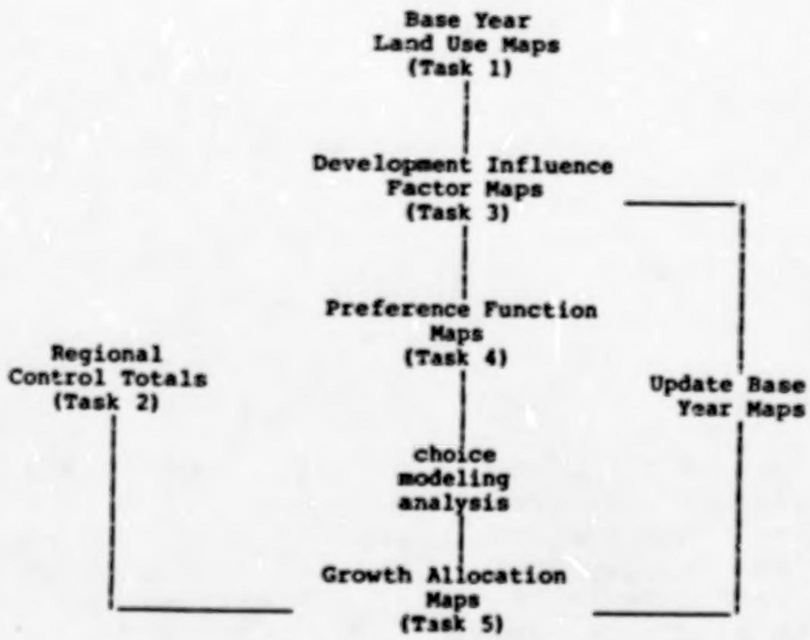

FIGURE I. LAND USE FORECAST PROCESS

2. BASE YEAR LAND USE MAPS

Land Use forecasts are produced for the 60 mile by 60 mile area of the Phoenix region that has the potential for being urbanized in the next fifty years. Ten major land uses, measured in acres, are allocated in five-year increments for four forecast periods. The time span of the land use forecasts is limited by the highway forecasts supplied by the local government since the transportation system is one of the most important factors in LUMOD.

Traditional land use models or growth allocation models (4), typically divide a metro area into districts with homogeneous socio-economic characteristics that must relate well to adjacent land uses and transportation systems. Major obstacles posed by conventional models are the delineation of homogeneous areas, the availability of corresponding data, and the inconsistency of allocating population and employment. LUMOD avoids these difficulties by defining the metro area in terms of physical characteristics: low-density commercial land uses, mobile homes, general industrial land uses, vacant land.

2.1 Homogeneity

LUMOD focuses on the homogeneity of land use classes, not of political or geographical districts. The land uses within a class possess similar locational requirements allowing the assignment of a set of preferences to each class. Unconcerned with homogeneous districts, LUMOD separates the Phoenix metro area into a uniform grid of 57,600 forty-acre parcels, a unit of measurement by which other SRP departments collect electric load data.

2.2 Data Collection

Data collection for LUMOD is achieved by entering a picture of land uses into the computer from aerial photographs. Thirty-three land use codes are digitized from the photos into shapes, or polygons, as they are actually observed. The land use code file is converted to thirty-three map-image files. These maps can be viewed in MAPCALC (5), an interactive graphics program developed at SRP that calculates and integrates any spatially-related data such as electric load, runoff, assessed valuation and transportation availability.

In MAPCALC, the thirty-three land use codes are aggregated to ten major land use classes (Table I) for the forecast process. Figure II is a 1987 base year map of low-density residential land uses produced in MAPCALC.

LAND USE	DESCRIPTION
Residential	
low-density	houses on more than one half acre
medium-density	typical subdivisions
high-density	apartments,townhomes,condominiums
mobile homes	mobile homes, travel trailers
Commercial	
low-density	neighborhood retail, services
medium-density	strip commercial development
high-density	mall, hospitals, high-rise office
Industrial	
light	industrial and business parks
general	conventional industrial
Vacant	
vacant	land available for development (including agricultural)

TABLE I. LAND USE CLASSES

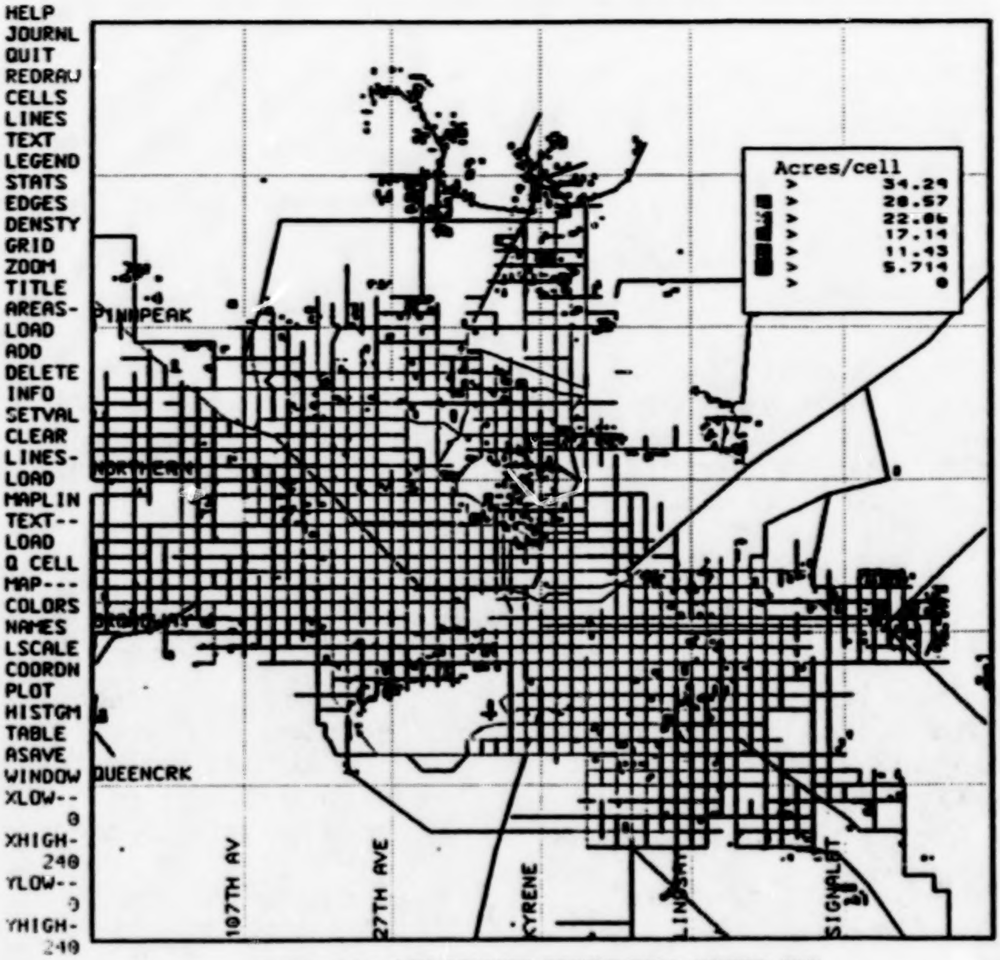

FIGURE II. LOW-DENSITY RESIDENTIAL FACTOR MAP

2.3 Allocation Inconsistencies

The amount of growth to be allocated for each forecast period is an input to a land use model. Consistency is difficult, and nearly impossible when allocating population and employment to predefined districts. "The model builder must resort to placing arbitrary carrying capacities on each zone in order to constrain the allocations. (He) must then determine the combination of population and employment that can be allocated to a zone without exceeding the carrying capacity of the zone." (6)

Allocating land use acres to forty-acre parcels provides LUMOD with a mathematical consistency. The sum of all land uses dispersed to a parcel, plus the existing land uses in the parcel, must total forty acres; and the sum of all allocations must equal the externally forecasted acres for all land uses.

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3. REGIONAL CONTROL TOTALS

LUMOD is a growth allocation model, not a projection model; it predicts the distribution of growth not the amount of growth. LUMOD accepts an externally determined level of growth for each land use class as an input, dispersing these acres according to predefined preferences attached to each land use class.

The forecasted acres for the ten land use classes control the quantity of growth in the metropolitan area and are referred to as regional control totals. The control totals for the base year are extracted from the base year land use maps (digitized from aerial photos) and are increased for each forecast period according to the growth of related attributes (see Table II).

Land Use Class	Forecasting Measure
low-density residential medium-density residential high-density residential mobile homes	population forecasts, housing density forecasts, people per acre forecasts, vacancy rate forecasts, housing mix forecasts
low-density commercial	medium-density residential forecasts
medium-density commercial light industrial	employment forecasts (minus manufacturing and construction)
high-density commercial	knowledge of future projects and expansions
general industrial	combination of manufacturing employment forecasts and knowledge of future projects and expansions

TABLE II. REGIONAL CONTROL TOTALS

4. DEVELOPMENT INFLUENCE FACTOR MAPS

The type of development which occurs within a forty-acre parcel depends on the characteristics of the parcel, the characteristics of adjacent and surrounding parcels, and the accessibility of the parcel to other land uses within the region. Some factors influencing development include proximity to transportation facilities, accessibility to employment, areas of redevelopment and adjacency to highways, freeways and intersections.

These geographic variables can be coded into map-image files or calculated from existing base year and forecast land use maps using MAPCALC. In addition to recalling, storing and displaying maps, MAPCALC offers many of the same operations as a hand-held calculator. It adds, subtracts, multiplies, divides, thresholds, scales, and convolutes maps, performing calculations on each 40-acre parcel (57,600 times). MAPCALC is a successful interactive program because the commands generally execute in less than two seconds.

The convolution command sums the number of acres of a land use within a specified radius of a current parcel and assigns the sum to the current parcel (again, this task is executed 57,600 times). A convoluted map provides a user with useful proximity information which is one of the most popular characteristics influencing locational decisions.

Proximity to railroads, freeways and major streets greatly influence a parcel's attractiveness for development. For example, a developer prefers to locate a grocery center adjacent to a subdivision of homes, however within close proximity is acceptable. A positive value is attached to a close-proximity factor map of medium-density residential land uses (fig. III) for low-density commercial uses.

5. PREFERENCE FUNCTION MAPS

"The practical usefulness of a model depends largely upon how successfully the real world is captured in the functional relationships of the model" (7). These relationships are defined as weighted combinations of factor maps or independent variables. Ten preference function maps or dependent variables are calculated, including a preference function map for vacant, developable land.

The selection of factor maps and the estimation of coefficients are based on the analyst's intuitive perceptions of

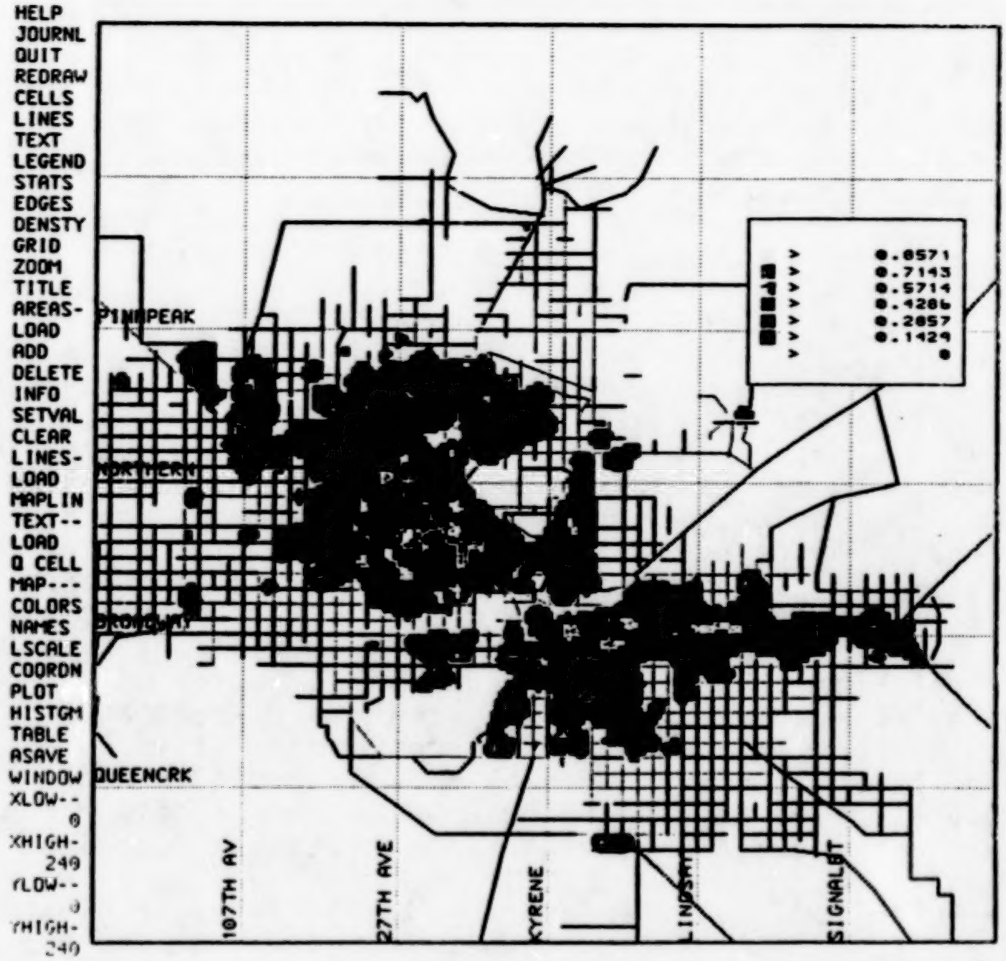

FIGURE III. HOUSEHOLDS WITHIN 3 MILES

the land use structure. Using the interactive environment of MAPCALC, strong and weak factor maps can be visually distinguished as well as the appropriateness of certain factor maps in defining the functional relationship of a land use.

A preference map should reflect observable locational behavior. For example, builders of typical subdivision homes (medium-density residential) search for vacant lots near, but not adjacent to freeways, lots accessible to employment opportunities, but not adjacent to major streets, intersections and railroads. The medium-density residential preference function map is composed of positive parameters for three factor maps:

- employment accessibility
- household proximity
- recent residential growth areas

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and negative coefficients for five factor maps:

- highway adjacency
- proximity to railroads
- intersections
- industrial proximity
- proximity to high-density commercial

An important aspect of the LUMOD is the inclusion of a vacant land preference function map. Developers may retain parcels of land in an undeveloped state until the market can absorb another development. A vacant land preference function map is included in the forecasting process so vacant land can also compete to remain undeveloped.

6. Forecast Allocation

The regional control totals are allocated using a choice modeling technique in which the ten land uses compete for the vacant, developable land available. Although some vacant parcels are useful for only one land use, the majority of developable parcels have the potential for a mixture of residential, commercial or industrial development. LUMOD allows simultaneous competition among parcels to receive an allocation, and among land uses to occupy a parcel.

The competition of land uses is based on a comparison of preference function maps for each land use type, but it is constrained by two primary considerations. First, the total acreage of all land uses (including vacant land) allocated to any forty-acre parcel must equal the amount of developable land within the forty-acre parcel. Second, the sum of the allocations of each land use type must equal the regional control totals.

Output from LUMOD consists of ten delta maps of allocated growth for each of the four forecast periods. These delta maps can be added to their corresponding base year maps to achieve the total land use acreages of any land use for a given forecast period. Figure IV shows the 1992 delta forecast for low-density residential land uses.

After the delta forecast maps are created for the first forecast period, the base year maps, factor maps and preference function maps are recalculated based on the forecasted growth of the previous period so the allocation in one period will influence the allocation in a subsequent period.

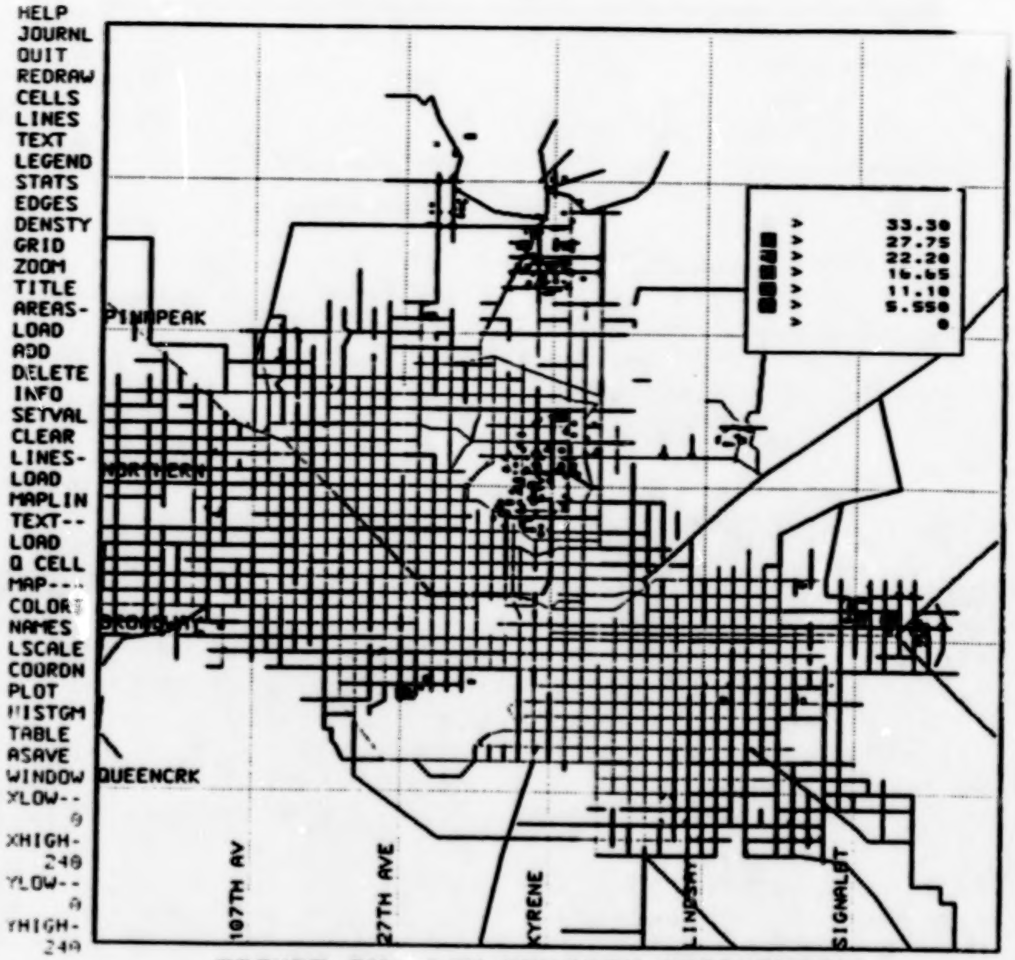

FIGURE IV. LOW-DENSITY RESIDENTIAL
1990 DELTA FORECAST MAP

7. APPLICATIONS OF THE SRP LAND USE MODEL

LUMOD was originally developed to study the future electrical power needs of the rapidly growing Phoenix metropolitan area. Forecasted patterns of land use were analyzed according to residential, commercial and industrial growth to size and locate new substations and distribution systems.

7.1 Densities, Masks and Sums

Acreages can be easily converted to other measures by multiplying the land use maps by density per acre maps. For example, a forecast of the number of households can be calculated by developing a housing unit per acre map for each of the four residential land use maps, and then multiplying these density maps by corresponding base year and forecast delta maps. Land use forecasts can also be

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analyzed in terms of population, customer service trips, or electric load, by multiplying any land use map by the appropriate density map.

Customer growth within SRP's electrical service area is difficult to predict manually due to it's unconventional boundaries; SRP services the metro area minus eight city centers. A forecast of the number of customers in the SRP service area can be easily calculated using LUMOD forecast maps and a 'mask' map of SRP's service area digitized in MAPCALC. Since the values of parcels in a mask map are either zero or one, multiplying a service area mask map by any of the land use forecast maps defines only those acres in the SRP service area. As mentioned earlier, acres can be easily converted to households/customers.

While zero/one maps can be used to mask one item, MAPCALC can extract the number of acres for multiple polygons. For instance, MAPCALC can sum the number of any land use acres by city if each city is digitized as a separate polygon. Acres can also be summed by census tracts, traffic area zones or any other geographical or functional description.

7.2 Departmental Uses

Applications of the land use forecasts within SRP were first limited to departments wanting predictions of future land use patterns. These users requested tabular data and used the land use maps for visual clarity of the data. Slowly, requests were received that stretched the capabilities of the Land Use Model.

- The Power Systems Analysis Group converted the ten land use forecast maps to electrical load maps using load per acre rates developed by their engineers.

- The Water Group Management Staff is generating a Water Demand Model for the Arizona Department of Water Resources by multiplying the LUMOD forecasts by maps of water consumption rates. The Water Demand Model will be able to forecast site-specific water demand.

- The Environmental Analysis Department tagged satellite temperatures collected by square kilometer to major land uses (residential, commercial and industrial) to analyze the effect of specific land uses on regional weather patterns.

- The Systems Planning Division purchases vacant land for the right-of-way of electrical power lines. The earlier the land is purchased, the cheaper the price.

- The Water Group monitors the conversion of agricultural land to urban land to understand the changing pattern of irrigated water use in the metro area. Urbanization of the Valley can be measured by substracting the forecast delta maps from the base-year Agriculture code map.

- SRP has begun a 'regionalization' program to decentralize its construction and maintenance crews, customer service offices and meter reader stations to bring them closer to the customers. The capital costs incurred in this program necessitate accurate forecasts of future land uses.

7.3 Political Scenarios

The effect of political scenarios on land use patterns is measurable by changing inputs to the forecast process. Certain projects can be 'forced' into the model and the subsequent surrounding development viewed:

- Despite the fact that Phoenix is a large metropolitan area, it has been void of freeways. Citizens finally agreed to finance the construction of 67 miles of freeways within the metro area over the next twenty years. The timing of certain stretches of the freeway is critical to growth patterns; some schedules have already been changed due to political pressure by landowners. Any freeway completion schedule can easily be input to LUMOD as a factor map.

- The Rio Salado Development Masterplan calls for 40 miles of mixed land uses to be developed in the Salt River riverbed over a period of fifty years as a solution to the flood control problems experienced in the past. The degree to which the Rio Salado Development improves land along the Salt River can be measured by forcing the Masterplan into LUMOD for specific forecast periods.

8. SUMMARY

The versatility of LUMOD lies in its ability to manipulate spatially disaggregated land use maps; the accuracy and reliability of the forecasts are attributable to the simultaneous competition of land uses for vacant land; and the success of LUMOD resides in the diverse applications by its users.

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THE NATURE OF SOIL DATA IN GIS -- ERROR OR UNCERTAINTY

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ABSTRACT

Soil data is crucial for almost any application of GIS technology to natural resource planning. It is also a basic data item in LIS applications, such as taxation of agricultural land. The source of the soil data has, however, tended to be used without regard to its inherent limitations. This paper reviews some of the more important of those limitations that are well known to soil scientists but may not be so familiar to others, it goes on to look at some of the suggestions that have been made as to how to improve the data, and the usefulness of those suggestions. Finally the paper suggests an alternative to these ideas, using knowledge integration and inference engine development.

1. INTRODUCTION

The layer of data in a Geographical Information System which receives the label soil, is generally crucial to applications in the management of natural resources (3, 4). From it, most obviously, landuse planning decisions may be made, relating to agricultural landuse (3), particularly parcels being ascribed as suitable for specific or general purposes, but farm land could also be assessed for taxation (12) and recreational management decisions made. Since the soil data is in use so often, it might be supposed that it is reliable. This is not, however, the case. Soil Surveyors are fully aware of the limitations of the maps they produce, but the reporting, publication and cartographic conventions governing the dissemination of this data are such that those limitations seem rarely to have been transmitted to any users, whether of the original paper maps or of the more recent digital data (17).

Map unreliability has been the subject of considerable research among the soil science community. Various advanced statistical treatments have been advocated as providing an improved methodology for mapping soils. Generally the soil data, faults and all, have continued,

however, to be freely incorporated in Geographical Information Systems as if they were accurate, and used accordingly in the types of analysis mentioned above. The inaccuracies in the soil maps may, however, be sufficient in certain conditions to invalidate the analysis, at best causing poor cropping, at worst causing failures in filter fields, building on inappropriate soils, or substantial over taxation.

This paper reviews first the nature of the problem, demonstrating the soil scientist's awareness of the problem. It then goes on to examine the statistical methods suggested as an improved methodology. The problems of these methods is noted, and an alternative methodology which would allow improvement of existing data is discussed.

2. SOIL MAPPING

The fundamental soil data imported to a Geographical Information System are the polygons shown on soil maps (e.g. 7). All such polygons or soil mapping units (whatever the scale) are represented as being the soil type which the soil surveyor who prepared the map believed to be most common or in smaller scale maps to be most representative.

There are a number of different types of soil map available. The most detailed is the Soil Series and Phase map (Table 1), now produced at a standard scale of 1:15,840. This map shows soils at the elementary category of classification, the soil series, and even the sub-series level, the Soil Phase (Table 2).

TABLE 1

Usual soil mapping units according to map scale (24)

Soil Mapping Units	Map Scale (lower limit)
Soil Series & Phase	larger than 1:10,000
Soil Series, Phase & Complex	1:10,000 to 1:50,000
Soil Series & Complex	1:50,000 to 1:100,000
Soil Association	1:100,000 to 1:250,000
Soil Order & Great Group	1:250,000 to 1:1,000,000
Soil Order & Suborder	smaller than 1:1,000,000

TABLE 2

Hierarchy of soil classification, giving increasingly detailed levels: as used by the U.S. Soil Conservation Service (16), a similar scheme is used in other countries.

Soil Order
Soil Suborder
Soil Great Group
Soil Subgroup
Soil Family
Soil Series
Soil Phase

On smaller scale maps, the soil mapping unit changes (Table 1), so that at 1:50,000, for example, Soil Series and Soil Complexes are shown. While on a map of a whole county, at perhaps 1:190,080, generalization is necessary and only Soil Associations can be delimited (e.g. 7), where a soil association is a mixture of soil series (Table 3) which may have some general similarity, but are more usually a cartographic artifact, not a pedological one. The occurrence of a Soil Association is therefore solely dictated by the cartographic limitations of how much area it is possible to show on a map of a particular scale (13, 15). At still smaller scales it is usual to map categorically more generalized soil units, so that on the 1:20 million soil map of the U.S. Suborders and Great Groups are shown (16, p412). All generalizations from the series map acknowledge the inherent impurity of the mapping units in the legend of the resulting soil map, since they always represent a mixture of soils at a categorically finer resolution, i.e. Soil Associations contain Soil Series, Soil Groups contain Soil Subgroups, Families and Series. The legend acknowledgement of impurity of the generalized maps, implies that at the more detailed level, the data is pure, i.e. an area mapped as one Soil Series does indeed contain only soils of the properties described.

3. DATA RELIABILITY AT THE DETAILED LEVEL

Objective, statistical analysis of the soil mapping units at the series level, also known as polypedons, have repeatedly shown that in most instances, this assumption is not valid, and within the mapped polypedon soil properties are not uniform within definable limits so that some pedons, sometimes the majority, fall

outside the definition of the mapped soil series (11, 14, 18, 22). That is not to say that all polypedons are grossly impure, but most contain 'noise' from other soil series, which may be significantly differ-

TABLE 3

Definitions of complex, commonly used soil mapping units

Soil Phase	--	a sub-set of the soil series having some characteristics such as hill slope or texture, making it distinctive.
Soil Series	--	is distinguished by a characteristic set of soil properties and is formed a particular parent material.
Soil Complex	--	two or more soil series in an intricate pattern, such that for cartographic reasons neither can be mapped individually.
Soil Association	--	a group of soil series placed in the same category due only to their proximity.

ent soil types (6, 10). Cartographic considerations and survey costs prevent portrayal of every last variety of true polypedon within a mapping unit, indeed studies have shown that the cost of attempting to delineate all soil variation in a given area is prohibitive in even a research environment, unless that is the sole object of the research (5). Essentially soils are simply too complicated for a county choropleth soil map at a scale of 1:15,840 to depict the full significant variation.

Soil maps are thus essentially unreliable as predictive models of soil occurrence. With even the most detailed maps, and certainly with standard county soil maps it is not possible on the basis of the information presented alone, to say that if someone goes to location X they will find soil Y. This uncertainty is acknowledged by the soil surveyors, and the soil survey report often includes discussion of the conditions under which other soil types will be found. Thus in the published soil survey of Medina County, Ohio, the Bennington Series, Phase A mapping unit with slopes of 0-2 per cent,is described thus:

> Included with this soil in mapping are small ponded areas that have a slightly darker colored surface layer and are wetter than is typical of Bennington soils. Also included are a few low knolls that have slopes of slightly more than 2 per cent and a few small areas of the more silty Tiro soils (7, p67).

while Bennington Series, Phase B mapping unit with slopes 2-6 per cent is described like this:

> Included with this soil in mapping are small areas of moderately well drained Cardington soils in the steeper places. These steeper places are commonly more eroded. Also included are spots of wetter soils in depressions and along waterways. The silt loam surface layer is commonly thicker in these areas of wetter soils (7, p67).

These will be commented on further below, but modern Soil Conservation Service Reports all include such statements, as do reports by, for example, the Soil Survey of England and Wales, to name just one overseas organization. It is therefore clear that the soil surveyor is fully aware of the unreliability of the map he has generated, and is textually attempting to set limits on the accuracy by naming at least the major 'impurities'.

Some writers have advocated reporting the probability of soil x being at a location where it is mapped. This would be more useful than the nothing sometimes reported, but, because in the different areas mapped as unit X there is certain to be a different probability of X occurring; it oversimplifies the variability of soils, while attempting to be complex.

4. ALTERNATIVE APPROACHES

Alternative approaches which have been explored by researchers concerned with the reliability problem in soil maps may be divided into two types: those exploring multivariate spatial variability, and those for single parameter variation. Earlier work concentrated on the first of these and is epitomized by the research monograph on the subject by R.Webster (18). Such methods as multivariate classification and ordination were widely used by these workers, both to show the unreliability of conventional maps, and to demonstrate an alternative

approach to preparing soil maps (20). The methods, however, usually lacked a spatial element, although some methods of spatially weighted classification were explored. Furthermore, it was usually found that the methods did not support the more visual classification of the fieldworker. These methods continue to be explored in the literature, but the analysis of single parameters has become increasingly important.

Single soil parameters have been advocated by many researchers as an desirable alternative to the standard soil series map. The problem with single parameter mapping is accurately interpolating values from sampled to unsampled locations. Early attempts used trend surface analysis, and like many analyses based on that ill fated method, they were found to be wanting in their precision, and anyway the simple polynomial model was seen as insufficiently flexible for the complex soil (18). Advanced geostatistical method involving analysis of the semi-variogram and kriging have since been widely applied to soils with considerable success (1, 2, 19, 21, 23). These methods assume that the variation over an area may be split into two components, systematic and random variation. The elements of these can be found from the semi-variogram an applied to the kriging model to produce the 'optimal' estimate of values at unsampled locations. Indeed on the few reported occasions when the interpolating power of different methods have been compared, kriging has sometimes proved itself to be the most reliable (9), but not always (8).

Within present general purpose GIS kriging, however, only has limited usefulness since it produces a reliable isarithmic map of soil properties, which is usually univariate, although by kriging principal component scores, for example, it could be multivariate. This is not a soil map in the conventional sense, and would not be recognized as such by some soil scientists, let alone by others. Furthermore, it and the other statistical methods mentioned rely on the measurement of continuous variables at systematically located points as the basic data unit. Collection of such point data has not been part of the usual soil survey, to date. Observation points have not been positioned systematically, only recently have detailed records been kept, and anyway no attempt has usually been made to even make observations of all areas delimited on the soil map. Thus for specific studies and research where suitably located samples are measured for continuous variables, the

methods of classification, kriging and the others are the most appropriate methods of analysis. They do not, however, provide an improved methodology for either the producer of a general purpose soil map or the user of a general purpose GIS (as implied by 3). Indeed, any attempt to implement these methods would necessitate ignoring the data held in present soil data and soil maps, and their replacement with an entirely new set of data recorded at and stored for each point. In the long term this may indeed be a desirable goal, but in the short term, it is wholly impractical for most users of soil data within a GIS.

5. THE 'INTELLIGENT' DATABASE ALTERNATIVE

In place of the statistical methods discussed above, an alternative approach is advocated here. It has been noted that the field surveyor who originally prepared the map, which is then input to the GIS, is more often than not only too well aware of the unreliability of the predictive model that the map purports to be. Indeed, in the better quality surveys the unreliability is reported by commenting on the purity of the mapping units, the nature of inclusions, etc. In Section 3 such a report is quoted form the Medina County Soil Survey Report, Ohio. The observations for Phase A can easily be turned into rules thus:

1.
```
IF      the area is ponded (a depression)
THEN    the soil is wetter than normal
AND     the surface horizon is darker than normal;
```
2.
```
IF      the slope is over 2 per cent
THEN    the mapping unit should be Bennington,
        Phase B; and
```
3.
```
IF      the parent material is silty
THEN    the soil is Tiro;
```

and for Phase B thus:

4.
```
IF      the surface is steeper than usual in the
area
THEN    the soils are Cardington; and
```
5.
```
IF      the area is a depression
OR IF   the area is a drainageway
THEN    the soil is wetter
AND     the surface layer is thicker.
```

These rules can be recorded as part of the geographical database, so that when soils of the Bennington series Phase B, for example, are part of an analysis of site suitability for building, it can be reported that in some areas the soils actually are suitable for building construction, although most of the area has moderate to severe limitations for this use (Cardington soils have only slight to moderate limitations).

It is possible to use these rules in at least three further ways:

1. Other layers within the GIS are likely to include elevation (a DEM). Reference to the elevation layer of the GIS will be able to determine whether any location is within a depression or drainageway (given the ability to produce profile and drainage maps), and the slope angle at that location. It would even be possible to find the average slope angle within a mapping unit, and locate those areas with extreme slopes. Thus all the topographic inquiries related to the rules above can be determined from the DEM. If, therefore, the rule base is supplied with an inference engine which can interrogate and recover answers from other layers of the GIS, it would be possible to delimit those areas where noise in the mapping unit is likely to occur. All rules above except rule 3 could be answered by access to the DEM. Rule 3 would require a data layer of soil parent material, possibly geology. This assumes that the spatial resolution of the topographic data would be superior to that of the soil map, and exploration suggests that it is, depressions and drainageways being identifiable within Bennington series soil mapping units, the geological data is, however, less likely to be so useful.

2. Since the only thing that separates Bennington Phase A from Phase B is the slope angle, it would be possible to fuse the two mapping units at the time of digitization, thus saving on computer storage requirements for the soils database, given that the data were stored in a vector format, or any raster format other than coding by individual grid cells. The two phases could easily be recovered by simply delimiting the areas with slopes less than and greater than 2 per cent. Whether the storage saved would in any way make up for the storage of the rules and the time taken in rule processing has to be seen by experiment, but it is

believed that the storage saving could be substantial on a county soil map, with reductions in the number of mapping unit of about half being possible.

3. Finally, the rules may form the basis of mapping unit selection for map display at a variety of scales, even scales larger than the original scale of digitization, because the rules allow delimitation of mapping units which were not shown at the smaller scale of map preparation. While this is objectionable to most cartographers it is technologically possible and done regularly; it might be better to enable an informated division of the map than not.

The above methodology is not solely applicable to soil data within GIS. The basic theory is equally applicable to vegetation, to geology, to landuse, etc. Since it accesses the real knowledge of the surveyors who originally prepared the map, and not the cartographic limitations on that knowledge, it could represent a viable mechanism for determining actual environmental parameters, such as soil type, at a location.

6. CONCLUSION

The errors that have been reported in many investigations of environmental layers within GIS, are primarily a function of the scale of production of the original map. The original surveyor, in many instances, is only too well aware of the limitations of the map; it is the unreserved use of the map data in the GIS that is at fault. Thus it is not the map that is in "error", it merely contains a considerable level of uncertainty or unreliability that should be incorporated as an inherent part of the spatial database.

Research to date which has looked at the problem of unreliability in environmental maps has taken a rigorously statistical approach to the problem, employing such methods as multivariate classification, and kriging. These methods supply the maker of a new survey where data is collected with these methods in mind, a powerful suite of tools for predicting the occurrence of phenonema at unsampled locations. It has been argued, however, that they do not answer the problem of unreliability in extant surveys, which are usually presented as maps, and used as input to GIS. It is suggested that organization of the reported impurities in mapping units, may form a knowledge base which can be

used used in an 'intelligent' geographic database, given the development of an appropriate inference engine.
This 'intelligent' database would enable:
1. the recognition of areas in the original mapping units where parameters other than those naming the mapping unit occur;
2. the reduction in mapping units and so reduction in storage requirements; and
3. data display at a variety of scales both smaller and larger than the original digitized map.
The approach is applicable to most layers of environmental data within a GIS.

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CONTINUED DEVELOPMENT AND APPLICATION OF A STATEWIDE LAND USE DATA BASE AND ANALYSIS SYSTEM

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ABSTRACT

The Geo-Facilities Planning and Information Systems Center at the University of Florida has developed a statewide land use data base and software package for use with microcomputers. The data base indicates the intensity of the dominant land uses in each of Florida's 67 counties. The software developed at the center allows for interactive access, display, and mapping of land use data on an IBM PC-AT or compatible computer.

The Florida Department of Environmental Regulation (DER) provided initial funding for the development of the data base. The DER is currently utilizing the system in the creation of a ground water well monitoring network. In this particular application, a land use layer is combined with hydrogeologic information to identify areas for future study.

The Center plans software enhancements which will allow users to create individualized displays and maps by combining the land use data base with their own data sets. Future applications include environmental and growth impact analysis, as well as a merger with remotely sensed data.

1. INTRODUCTION

The Florida Department of Revenue (DOR) requires each county property appraiser's office to annually update and maintain an ad valorem computer tax tape. These tax tapes contain land use informatiom for each of Florida's approximately 7 million parcels. Each parcel is classified by one of 100 land use types (fig 1), as well as other data including dollar value, building area, and parcel size. In order to create the land use data base this information is then combined with a georeferenced data set derived from the Public Lands Survey System's (PLSS) township, range, and section grid coordinate system. A compact data base indicating the intensity of the dominant land use for each section of Florida has been formed, by aggregating all parcels with the same land use within each section.

2. DATA BASE DEVELOPMENT

All of the parcel information for the land use data base is drawn from the DOR tax tapes, prepared by the county property appraisers. Detailed parcel information is placed on the tax tapes in a consistent format specified by the DOR. Compliance with the format varies from county to county according to the level of automation in each property appraiser's office, making the interpretation of the tax tapes a time consuming task. Some counties have omitted important variables such as the parcel size and the age of structures from their tax tapes. In addition, some of the more labor intensive variables, exterior wall codes for example, are frequently missing from the tax tapes. Other variables, including assessed value and the owner's name and address are always present. Inconsistent coding of land use types from one county to the next and sometimes within individual counties has presented another obstacle to the interpretation of the DOR tax tapes. Broad "catch all" categories such as land use code 11 (stores, one story) also present a problem. This land use code is vague because it does not allow the property appraisers to distinguish between a free standing store and a commercial strip. This problem could be eliminated if Standard Industrial Classification codes were substituted for the commercial and industrial land use codes on the ad valorem tax tapes. In addition, this substitution would facilitate the merger of the tax tape data with census data such as the <u>County Business Patterns</u>. These anomalies require the Center to communicate directly with the county property appraiser

FIGURE 1. LAND USE CLASSIFICATION

RESIDENTIAL

00 VACANT RESIDENTIAL
01 SINGLE FAMILY
02 MOBIL HOMES
03 MULTI-FAMILY >10
04 CONDOMINIA
05 COOPERATIVES
06 RETIREMENT HOMES
07 BOARDING HOMES (INSTITUTIONAL)
08 MULTI-FAMILY <10
09 UNDEFINED RESERVED FOR DOR

COMMERCIAL

10 VACANT COMMERCIAL
11 STORES, ONE STORY
12 MIXED USE I.E. STORE AND OFFICE
13 DEPARTMENT STORE
14 SUPERMARKET
15 REGIONAL SHOPPING CENTER
16 COMMUNITY SHOPPING CENTER
17 ONE STORY NON-PROFESSIONAL OFFICES
18 MULTI-STORY NON-PROFESSIONAL OFFICES
19 PROFESSIONAL SERVICES BUILDINGS
20 AIRPORTS,MARINAS,BUS TERMINALS,PIERS
21 RESTAURANTS,CAFETERIAS
22 DRIVE-IN RESTAURANTS
23 FINANCIAL INSTITUTIONS
24 INSURANCE COMPANY OFFICES
25 REPAIR SERVICE SHOPS
26 SERVICE STATIONS
27 AUTOMOTIVE REPAIR, SERVICE, AND SALES
28 PARKING LOTS, MOBILE HOME SALES
29 WHOLESALE, MANUFACTURING, AND PRODUCE
30 FLORIST, GREENHOUSES
31 DRIVE-IN THEATERS, OPEN STADIUMS
32 ENCLOSED THEATERS AND AUDITORIUMS
33 NIGHTCLUBS, BARS, AND COCKTAIL LOUNGES
34 BOWLING ALLEYS, SKATING RINKS, ARENAS
35 TOURIST ATTRACTIONS
36 CAMPS
37 RACE, HORSE, AUTO, AND DOG TRACKS
38 GOLF COURSES
39 HOTELS, MOTELS

INDUSTRIAL

40 VACANT INDUSTRIAL
41 LIGHT MANUFACTURING
42 HEAVY MANUFACTURING
43 LUMBER YARDS, SAW MILLS, PLANING MILLS
44 FRUIT, VEG., AND MEAT PACKING PLANTS
45 CANNERIES, DISTILLERIES, AND WINERIES
46 OTHER FOOD PROCESSING
47 MINERAL PROCESSING
48 WAREHOUSES AND DISTRIBUTION TERMINALS
49 IND STORAGE (FUEL,EQUIP,AND MATERIAL)

AGRICULTURAL

50 IMPROVED AGRICULTURE
51 CROPLAND SOIL CLASS 1
52 CROPLAND SOIL CLASS 2
53 CROPLAND SOIL CLASS 3
54 TIMBERLAND
55 TIMBERLAND
56 TIMBERLAND
57 TIMBERLAND
58 TIMBERLAND
59 TIMBERLAND
60 GRAZING LAND SOIL CLASS 1
61 GRAZING LAND SOIL CLASS 2
62 GRAZING LAND SOIL CLASS 3
63 GRAZING LAND SOIL CLASS 4
64 GRAZING LAND SOIL CLASS 5
65 GRAZING LAND SOIL CLASS 6
66 ORCHARD GROVES, CITRUS
67 POULTRY, BEES, TROPICAL FISH, ETC.
68 DAIRIES, FEED LOTS
69 ORNAMENTALS, MISCELLANEOUS AGRI.

INSTITUTIONAL

70 VACANT INSTITUTIONAL
71 CHURCHES
72 PRIVATE SCHOOLS
73 PRIVATE HOSPITALS
74 HOMES FOR AGED
75 ORPHANAGES
76 MORTUARIES, CEMETERIES
77 CLUBS,LODGES, AND UNION HALLS
79 CULTURAL ORGANIZATIONS

GOVERNMENT

80 UNDEFINED
81 MILITARY
82 FOREST, PARK, AND REC. AREAS
83 PUBLIC SCHOOLS
84 COLLEGES
85 PUBLIC HOSPITALS
86 OTHER COUNTIES
87 OTHER STATE
88 OTHER FEDERAL
89 OTHER MUNICIPAL

MISCELLANEOUS

90 GOV OWNED LEASED BY NON-GOV LESSEE
91 UTILITIES
92 MINING, PETROLEUM, AND GAS LANDS
93 SUBSURFACE RIGHTS
94 RIGHT-OF-WAY STREETS, ROADS, AND CANALS
95 RIVERS, LAKES, AND SUBMERGED LANDS
96 SEWAGE DISP, BORROW PITS, AND WETLANDS
97 OUTDOOR RECREATIONAL

CENTRALLY ASSESSED

98 CENTRALLY ASSESSED

NON-AGRICULTURAL ACREAGE

99 ACREAGE NOT ZONED AGRICULTURAL

BEST COPY AVAILABLE

offices in order to reduce errors and time spent in the processing of individual tax tapes.

The information on the DOR tax tapes are processed into a consistent format and an abbreviated version. The reformatted data set contains all of the essential parcel attributes that are used to determine the intensity of each land use. The intensity of the land use is determined by several variables including assessed value, acreage, square footage of building area, and the number of occurrences. Also included in the reformatted data set is the age of any structures on each parcel, tax exemption codes, and the last recorded sales date of each parcel. From the reformatted data set two more data sets are formed, the non-residential data set and the section summary data set.

The non-residential data set contains the same land use attributes found in the reformatted data set, but excludes all residential land uses. The non-residential data set has land use information on each commercial, industrial, agricultural, governmental, and institutional parcel in Florida. This data set is about one tenth the size of the reformatted data set and therefore can be stored on two 2400' computer tapes. These tapes can then be accessed on a mainframe computer to obtain land use information at the individual parcel level. For example a list of the names and addresses of all owners of restaurants in a specific county or the entire state can be generated and then down-loaded to diskettes.

The section summary data set, as mentioned above, is created from the reformatted data set. The section summary data set contains the land use data and locational information of all the residential and non-residential parcels in Florida, aggregated to the section level. The average size of a section summary data set for an individual county is 300K. The section summary data sets for each county are then down-loaded for direct access on a micro computer.

Geographic representation within the land use data base was initially achieved through a coordinate data set,

mathematically generated from the PLSS. The sytematic pattern of townships, ranges, and sections in the PLSS makes it possible to quickly create a correct ordinal coordinate data set. However, due to survey errors and the pre-existance of Spanish land grants which were incorporated unchanged into the original survey, the pattern of the PLSS has been disrupted. As a result, it was necessary to replace the ordinal data set with a new coordinate data set digitized by the Florida Resource and Environmental Analysis Center at Florida State University. The coordinate and section summary data sets for an each county easily fit onto a 1.2 mg floppy disk.

3. HARDWARE AND SOFTWARE

The hardware necessary to develop the land use data base consists of an IBM PC-AT micro computer equipped with an enhanced graphics card and monitor, a 3278/79 coax card for linking the mainframe and micro computer, a color printer, and an eight pen plotter. This system is relatively inexpensive and adaptable to a number of uses. The hardware arrangement is ideal for district or regional offices where the majority of the data sets can be processed and then distributed to local offices for further processing or use.

The software is written in FORTRAN and the IBM Graphics Kernel System. The graphic kernel system, utilizing virtual device interface concepts, was chosen because it maintains the proper aspect ratio irrespective of the output device used.

The program is driven by menus that allow the user to select both the desired information and display format. A table of contents helps to guide the user through the various menus. The user first selects land use attributes from the distribution of data menu. The list of attributes includes the number of parcels, appraised value, taxable value, land value, square footage of building area, acreage, and ratio acreage. Next, the user inputs the desired land use, choosing from either residential, commercial, industrial, agricultural, institutional, governmental, and miscellaneous categories. An individualized subset may also be created from a single land use code or a group of codes. The user then selects a display format for the output, choosing either a map or tabular data

FIGURE 2. RESIDENTIAL LAND USE PATTERNS

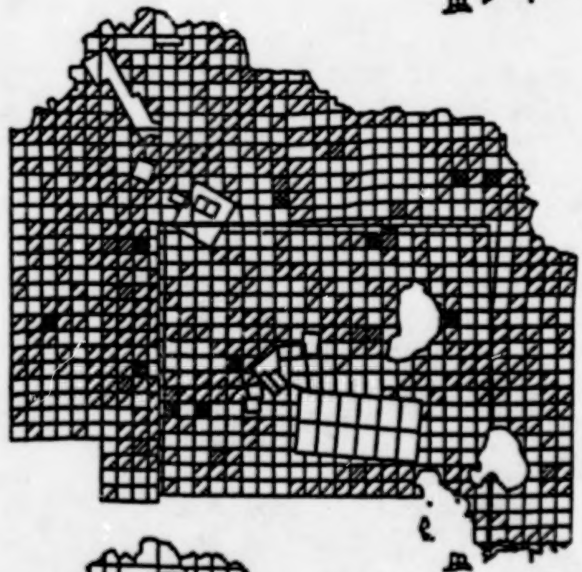
(a) Single-Family.

Number of Parcels
LANDUSE 01

100% = 1191

81	100
61	80
41	60
21	40
01	20

(b) Mobile Home.



Number of Parcels
LANDUSE 02

100% = 80

81	100
61	80
41	60
21	40
01	20

(c) Multi-Family.

Number of Parcels
LANDUSE 03

100% = 47

81	100
61	80
41	60
21	40
01	20

set. A wide variety of output devices are available for display of the requested format including a monitor, printer, plotter and disk drives. The parameters are then displayed, allowing the user to check default settings, set maximum values, or make any desired changes. These user responses generate a data string which is used by the summary and coordinate data base access program to generate a map or tabular output of the intensity of land use for the chosen land use codes. The data is displayed as a percentage of the section having the highest value of the land use selected. For example, if the user selects the number of parcels variable for land use code 14 (supermarkets), the section with the maximum number of occurrences of supermarkets would then be set at 100%, with all other sections displayed as a percentage of that maximum value.

4. APPLICATIONS AND EXPANSION

Analysis and manipulation of the land use attributes contained in the land use data base assists planners in developing a greater understanding of regional and statewide issues and trends. The data base displays and maps information at the section level for an average of one cell per square mile. Given the constraints of time, funding, and the large area of administration faced by state and regional planning agencies this scale is useful for many applications. Figure 2 provides an example of how the land use database may be used to analyze the land use distribution and growth patterns of a given county. Examining the residential land use patterns for Alachua County and the City of Gainesville, figure 2a illustrates that most multi-family housing is located in the city's central core. The central core is surrounded by zones of single-family housing, as displayed in figure 2b. Most mobile homes (fig 2c) are shown to be located in the outlying and rural regions of the county. A pattern of concentric zones becomes apparent as one travels from the downtown to the outlying regions of the county. The land use data base can be used to graphically represent growth and assist planners in understanding patterns of community development.

In Florida, the data base is now being used by the Department of Environmental Regulation (DER) and several of the regional planning councils. The DER is currently using the land use data base to assist the staff of its Ground Water Section, in the creation of a ground water well monitoring network. By

combining data from the land use data base with information on the geologic and hydrologic setting of a section, a priority well monitoring network is being established. The regional plannning councils are using the data base in a variety of applications which include the preparation of the land use elements of their comprehensive plans.

Tax tapes for the years 1984 and 1985 have been complelety processed. Additional years will be processed as time and funds permit. The accumulation of land use data from year to year will expand the the data base's trend analysis capability. By comparing data over time it will be possible to map, and graph the changing patterns in land use composition and value at the state, county, or section level.

In the near future, the USGS 1:200000 scale data base, which contains major transportation arteries and water bodies, will be incorporated into the coordinate data set. This combination will improve the visual reference points within the land use data base.

An additional application of significance will be the merger of the land use data base with remotely sensed data. The level of specificity inherent in the data base will improve the urban definition of the remotley sensed images. In addition, the merger will allow the data base to serve as an efficent and economical ground truthing device.

5. CONCLUSIONS

The land use data base and software described in this paper have broad applications potential, either as a stand alone system or as part of a larger geographic information system. The methodology described above should be repeatable in all states having the PLSS, a central repository of computerized ad valorem tax tapes, and a common land use coding scheme used by property appraisers.

One of the most attractive features of the land use data base

is its reliance on the ad valorem tax tapes. These tax tapes represent literally thousands of hours of data collection that has provided detailed information on approximately 7 million parcels over a wide geographic area. It is safe to say that this task could not be duplicated for purely research oriented activities, because the vast amounts of time and money involved in the collection of data on such a scale. Fortunately, all the variables required to produce a worthwhile land use data base, including spatial assignments, indicators of intensity, and thematic attributes, have been gathered by local governments.This means that a land use data base similar to the one described in this paper can be accomplished over a relatively short period of time with a modest amount of resources.

Experience has shown that while inconsistencies and problems do exist in the collection of data, the property appraisers offices are usually responsive to questions concerning their individual tax tapes. More significantly, continued use of the data has fostered increased uniformity and willingness on the part of the property appraisers to include land use information that is not directly related to property evaluation.

The most important benefit of the land use data base is its simplicity. The relative ease of devlopment and the wide range of micro computer applications has attracted both support and interest in the data base. The wealth of information available from the land use data base has aroused the curiosity of those agencies exposed to the product and prompted the exploration of more complex projects. On a more general level, the agencies involved have come to accept that the development of a geographic information system is an itterative process and that the benefits of a well designed system far outweigh the costs.

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RESEARCH IMPLICATIONS OF ELEVEN NATURAL RESOURCE GIS APPLICATIONS

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ABSTRACT

During the fall semester of 1986, a weekly series of lectures and discussions were co-sponsored by the Wisconsin Department of Natural Resources and the Institute for Environmental Studies of the University of Wisconsin-Madison. The seminar participants focused on the use of land information systems for natural resource applications, and the systems' operational requirements, implementation and maintenance costs, and impacts upon policy formulation and decision making.

Eleven different systems were reviewed and evaluated. These ranged in scale from state and regional to site specific applications. Common themes, problems and techniques have been identified and distilled. Issues varied from toxic waste disposal to ground water modelling; technologies reviewed included both vector and raster systems; system costs ranged from thousands to millions of dollars; and implementation strategies varied from systems being based on connecting high accuracy base maps, to regional and state systems using available data bases.

1. INTRODUCTION

The rationale for conducting a seminar in the application of geographic information systems (GIS) for natural resource planning, management, and monitoring stemmed from several sources. For two and one half years, the University of Wisconsin-Madison, Institute for Environmental Studies, has sponsored a weekly graduate seminar dealing with issues related to the design, development, and implementation of multipurpose cadastres and land information systems. Initially, the seminar brought in speakers from around the country to address these issues. Over one thousand persons attended during the first semester, leading to development of a cross-disciplinary group advocating land records modernization. The further evolution of this initiative led to formation of the Wisconsin Land Records Committee appointed by the Governor (Merideth et al., 1986). Subsequent seminars were used to involve state and local agencies, and for UW-Madison to develop its land information studies program. A new focus was needed, so we looked to involve a specific state agency.

The Wisconsin Department of Natural Resources (WDNR) had been collaborating with UW-Madison through the Land Information and Computer Graphics Facility, including the sharing of both digital spatial databases and access to geoprocessing software. WDNR had recently examined the operations of its bureaus to determine the potential for further development of GIS applications. There was a

need to increase the visibility of GIS potential, expand intra-agency awareness, and generally promote GIS literacy among potential users and managers. The opportunity for furthering UW-Madison WDNR collaboration was evident.

2. METHODS

Wisconsin DNR and UW-Madison jointly selected speakers to cover a spectrum of natural resource applications, and a sampling of software environments. WDNR provided funding, while UW-Madison coordinated logistics. Speakers submitted a written and illustrated paper at least two weeks in advance; these were reproduced and distributed in advance to seminar participants. Speakers arrived on a Thursday evening; dinner was used as an opportunity to discuss issues with agency GIS and applications staff, UW-Madison faculty and graduate students. (A significant sampling of local ethnic cuisine was accomplished!) Friday morning, the speaker toured WDNR bureaus and met with potential GIS users. Friday afternoon, speakers delivered slide-illustrated lectures and led discussions.

A strategic decision was made to offer the seminar at WDNR headquarters, about a half hour walk from campus, to encourage agency personnel to attend; this proved to work very well. Credit/nocredit status was available for both agency personnel and students. Attendance and a paper critiquing an individual speaker were the only course requirements. A four-person interagency panel was designated to review the presentations and deliver a summary seminar on the implications for development of natural resource GIS applications in Wisconsin. A proceedings of the seminar, including each speaker's paper, was edited and published by the Institute for Environmental Studies (Niemann and Sullivan, 1987).

3. PARTICIPANTS

Speakers included representatives of universities, federal agencies, multi-state regional agencies, state agencies, multi-county regional agencies, and a recently privatized national research center. In addition, introductory and summary sessions were held. During the course of the semester approximately 175 persons attended the seminar, including 24 who took the seminar for credit. The speakers, their affiliations, and topics are listed in Table 1.

Table 1: Seminar Speakers, Affiliations, & *Topics*

Al Vonderohe, Jerry Sullivan, Steve Ventura, University of Wisconsin-Madison
Application of Land Information Systems for Soil Erosion Planning in Dane County, Wisconsin

J. Terry Moore, Land Management Planner, Nicolet National Forest, U.S. Forest Service, Rhinelander, Wisconsin
Use of a Land Information System (MOSS) for Forest, Wildlife, and Recreation Planning and Management in the Nicolet National Forest

Bruce Rowland, Project Manager, Office of Natural Resources and Economic Development, Geographic Information Services, Tennessee Valley Authority (TVA), Norris, Tennessee
Use of a Land Information System and Computer Aided Design for Natural Resource Planning, Management, and Facility Design

Tom Patterson, Chief of Planning Research, Southeastern Wisconsin Regional Planning Commission (SEWRPC), Waukesha, Wisconsin
Development of an Automated Mapping and Land Information System: A Demonstration for the Town of Randall, Kenosha County

Ken Lanfear, Assistant to the Chief Hydrologist, Office of the National Water Summary and Long Range Planning, U.S. Geological Survey, Water Resources Division (USGS WRD), Reston, Virginia
Use of Geographic Information Systems for Long Range Water Planning and Management

Mike Kernodle, Senior Hydrologist, New Mexico District, U.S. Geological Survey, Water Resources Division, Albuquerque, New Mexico (USGS N.Mex.)
Use of a Geographic Information System for Groundwater Modelling

Edward Hillsman, Information Technology and Human Systems Group, U.S. Department of Energy, Oak Ridge National Laboratories (ORNL), Oak Ridge, Tennessee
Estimating Population at Risk from Release of Hazardous Materials

Warren Brigham, Project Manager for Natural Resources, Lands Unsuitable for Mining Program, Illinois Natural History Survey (Ill. NHS), Champaign, Illinois
Landscape Models from Geographic Information Systems: Fruit Salad from Apples and Oranges

Earl Nordstrand, Geographic Information Systems Manager, North Slope Borough (N. Slope), Anchorage, Alaska
Integration of Biological Survey Data with Geographic Information Systems and Data Base Management Systems

Alan Robinette, Director of Planning Information, Minnesota Land Management Information Center (Minn. LMIC), St. Paul, Minnesota
Development and Implementation of a State Land Information System for Toxic and Radioactive Waste Siting, Groundwater, and Forestry Planning and Management

Jon Corson-Rikert, Research Analyst, Harvard Laboratory for Computer Graphics and Spatial Analysis, Cambridge, Massachusetts
Updating Multi-layer Vector Databases and *Building a Database for Planning: Minute Man National Historical Park*

4. APPLICATIONS

The diversity of applications discussed is indicative of the legislative mandates encompassed by the Wisconsin Department of Natural Resources (fig. 1). Water resources applications were presented by USGS WRD, USGS New Mexico, and Minnesota LMIC. Soils and rural land management applications were presented by UW-Madison, Minnesota LMIC, and Harvard. Forestry applications were presented by the Nicolet N.F. and Minnesota LMIC. Wildlife applications were presented by the North Slope Borough and the Nicolet N.F. Toxic waste and pollution applications were presented by Minnesota LMIC and USGS WRD. Siting, facilities planning, and routing applications were presented by TVA, ORNL, Illinois NHS, and Minnesota LMIC. Land records and cadastral applications were presented by SEWRPC, UW-Madison, ORNL, and the North Slope Borough. Mining applications were presented by Minnesota LMIC and Illinois NHS. Parks and recreation and visual simulation applications were presented by Harvard.

	U. Wisconsin	Nicolet N.F.	TVA	SEWRPC	USGS WRD	USGS N. Mex.	Oak Ridge NL	Illinois NHS	N. Slope Bor.	Minn. LMIC	Harvard U.
water resources					●	●				●	
soils	●									●	
rural land mngt.	●									●	●
forestry		●								●	
wildlife		●							●		
toxic waste					●					●	
siting studies			●				●	●		●	
facilities mngt.			●								
land records	●			●			●		●		
mining								●		●	
parks/recreation											●
visual simulation											●

Figure 1: Matrix of Natural Resource Agencies x Applications Presented

5. SOFTWARE

The systems presented utilized several well known commercially available geoprocessing software packages (fig. 2). The ODYSSEY system was used at Harvard, U. Wisconsin, and SEWRPC. ESRI's ARC/INFO was the most widely used system, at both USGS WRD and USGS New Mexico, as well as Illinois NHS, Minnesota LMIC, and the North Slope Borough (later also available at UW-Madison). MOSS (Map Overlay Statistical System) was used by the Nicolet N.F., primarily because it was available within the public domain. TVA had acquired INTERGRAPH software, and significantly augmented the CAD capabilities to address GIS needs. SEWRPC continues to use CALMA software, but only for data entry; subsequently, they acquired DELTAMAP, a commercial MOSS successor, for this purpose. ORNL had developed extensive software capabilities in-house, but had not chosen to market such developments. Minnesota LMIC continues to use its EPPL (Environmental Planning Programming Language) for raster processing, particularly of statewide coverages, in tandem with the capabilities of ARC/INFO. EPPL is being actively marketed, now in pc form as well. USGS New Mexico found need to interface ARC/INFO with ISM (Interactive Surface Mapping) software for input to its finite difference modelling package. Harvard had perhaps the most active software research program, and in addition to ODYSSEY was utilizing a version of MAP (Map Analysis Package), in conjunction with IMAGO MUNDI (a shaded relief modelling package). Harvard is also developing ROOTS (a micro based digitizing/topological structuring package) as a module of the Army Corps of Engineers' GRASS (Geographical Resources Analysis Support System).

The applications to which these software systems have been put are presented in fig. 3. The software systems selected vary considerably in their spatial analytical capabilities. They are differentiated not only by dominant use of vector or raster data representations, but by use of spatial logic such as adjacency and contiguity relationships (topology).

	U. Wisconsin	Nicolet N.F.	TVA	SEWRPC	USGS WRD	USGS N. Mex.	Oak Ridge NL	Illinois NHS	N. Slope Bor.	Minn. LMIC	Harvard U.
Arc/Info	●				●	●		●	●	●	
Calma				●							
Deltamap				●							
EPPL										●	
Imago Mundi											●
ISM						●					
Intergraph			●								
MAP											●
MOSS		●									
Odyssey	●			●							●
Roots/GRASS											●
In-house							●				

Figure 2: Matrix of Natural Resource Agencies x Software Used

ODYSSEY (Chrisman, 1979; Morehouse and Broekhuysen, 1982) and ARC/INFO (Morehouse, 1985) rely on concepts such as spaghetti digitizing, automated topological structuring, automated error checking, and rapid processing of complex cases of polygon overlay. Both of these systems implement various tolerance distances and decision rules to weed spurious sliver polygons (fuzzy tolerance), close undershoots, trim overshoots, flag dangling linework, flag unlabeled or doubly labeled polygons, etc. MOSS, although available in the public domain (WELUT, 1982), relies on arc/node digitizing, requires redundant storage of nested polygons, and utilizes a less efficient polygon overlay algorithm. INTERGRAPH, though pursuing the development of topologically structured systems (Teng, 1986) has not yet demonstrated a successful implementation of fuzzy tolerances in polygon overlay. DELTAMAP (Deltasystems, 1986) offers little information about any improvements in the efficiency of data storage or in polygon overlay algorithms as compared to MOSS; it appears that Deltamap does not, however, consider fuzzy overlay, but still derives intersections from polygon by polygon comparisons.

In contrast to continuous representations of space are the discrete models based on rasters. In our examination of publicly available literature, we have seen little about the data structures or algorithms applied by ORNL. It is clear that ORNL has developed some sophisticated grid modelling algorithms. EPPL, developed by Minnesota LMIC, is a substantial contrast; its functionality is well documented and it is readily available in pc and mini form relatively inexpensively. The Interactive Surface Mapping (ISM) package is also not well known to these authors; it appears that its interactive contouring and grid interpolation from irregularly spaced points, and perhaps its perspective display of continuous 3D surfaces rather than merely 2D coverages, was essential in the given hydrologic application presented. (At the time, such functionality was unavailable within the ARC/INFO system; this application preceded the release of TIN, the triangulated irregular network module). MAP, available in various guises from both Harvard

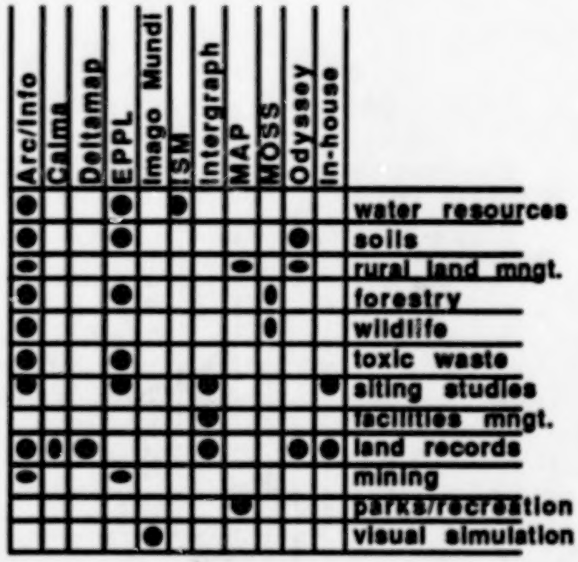

Figure 3: Matrix of Software Used x Natural Resource Applications

and Yale, offers considerable algorithmic flexibility, but appears to be seldom applied for anything larger than site scale applications. The linking of MAP capabilities with analytical relief shading provided in IMAGO MUNDI (White, 1985), provides considerable interest to resource managers who must present landscape interpretations. GRASS (Westervelt, Goran, Shapiro, 1986) an inexpensive public domain, grid based modelling package operating in a pc environment, offers further possibilities in terms of the display of vector data graphically superimposed with raster imagery. Although overlay analyses are still performed in a grid environment in GRASS, offering limited application for integration of resource and cadastral records, the augmentation of such capabilities with automated topological structuring during the digitizing/editing phase (White and Maizel, 1987) is exciting.

6. OBSERVATIONS

Following the semester's presentations, the interagency review panel met several times to discuss their observations and attempt to derive some general principles. The following is an outgrowth of these discussions with the review panel and class participants, summarized by the authors.

6.1 Level of Government

The committee making speaker selections was unable to identify successful GIS applications of a distinctly natural resource orientation *originating* from within local government. However, both the soil erosion application by the UW-Madison and the cadastral application by SEWRPC involved local government officials. The North Slope Borough of Alaska is certainly of a different scale than what would otherwise be considered local. This absence is probably indicative that this technology has not yet been made accessible in a sufficiently inexpensive yet analytically powerful commercial software package; there is evidence that this may change in the next few years.

6.2 Accessibility of GIS Technology

There was a prevalent belief from the various speakers that digital spatial data products will necessarily replace non-digital alternatives. However, virtually all speakers and panelists agreed that GIS are not yet mature. The technology is still relatively inaccessible to operational decisionmaking, and technical specialists remain the chief means of access for most users of digital geographic information. We will not be able to claim that GIS are truly successful until we see them integrated into the day to day activities of a broad base of natural resource agency personnel. Several participants expressed the attitude that no GIS with which they have had experience is sufficiently user-friendly.

6.3 Implementation Methods

Another theme dealt with the influence of upper management's perspective upon system evolution. In several cases the evolution of GIS capabilities resulted from a planned approach to dealing with data management needs. In many others the adoption of GIS was in response to an impending environmental and/or fiscal crisis. Some stated that the only way GIS became a reality within their organization was through the efforts of a "white knight", an upper level supervisor who became attuned to the benefits of adopting GIS and sold the concept internally.

6.4 Costs: Up-front and Ongoing

Other distinctions were drawn between the capability of federal agencies to essentially "parachute" a GIS into place by virtue of central decisionmaking authority and access to immediate funding, in contrast to the incremental approach usually found at state/local levels, where coalitions must be built to justify a system. System initiation was seen to be driven as much by political expediency as available budgets and scale of operation. Frequently, annual operating costs were described as equal to the purchase price of a system; hence, the need to cultivate support for the GIS throughout the organization.

6.5 Geometric Frameworks

Speakers varied in their expressions of the need for a geometrically solid, positionally accurate, and sufficiently reliable land base. All were interested in establishing a framework which they perceived as sufficient for their application, but this varied from those content to digitize control points from topographic quadrangles (at one or more scales), to those who insisted on prior remonumentation of the Public Land Survey System and calculation of geodetic coordinates for such a control framework. Applications ranged from those which had evolved from data sets compiled with the assumption that the PLSS was adequately represented as a regular grid lattice, to those that insisted that the coordinates stored for areal entities be adequate for mapping "at a scale of one to one".

6.6 Comprehensiveness vs. Redundancy

Some insisted on developing or contracting for complete coverages as quickly as possible, even at some loss of detail or positional integrity. They felt system support was enhanced if some type of analytical product was provided early on for everyone making an inquiry. At the other extreme were those who were reluctant to create redundant coverages at different scales, but preferred to inch forward.

6.7 Institutional Structures & Mandates

The deficiencies which speakers identified relevant to GIS functionality related primarily to institutional structures, rather than to GIS technology per se, such as data structures or algorithms. A

common complaint centered on the project by project nature of GIS activities they were authorized to conduct, as opposed to having a specific authorization to become involved in day to day, routine spatial data management functions. Those speakers representing more established GIS noted, however, that marketing is never over; in-place systems do not necessarily generate users. Hence, there is a dilemma that apparent success cannot be measured by existing data sets, but only by the continued demand for use and expansion from an informed clientele. The actual number of skilled users of a single system ranged from only a couple to over seventy.

6.8 Standards and Flexibility

A recurrent need was expressed for development of system protocols or standards to enable networks of parallel systems to evolve and yet remain compatible. Most users had experienced difficulty in having to develop data conversion and exchange tools for import and export between diverse software systems. While applications were predominantly oriented toward vector representation and analysis, others did not discount the need to maintain raster processing capabilities for resource applications and to remain sufficiently flexible to mix vector and raster modes in a single application, or to convert from one to the other.

6.9 Quality, Consistency, Maintenance

Speakers also agreed that data quality issues had not yet been adequately addressed by the vendors. Although topological and consistency checks are available, not all had made adequate use of these in structuring their databases. Issues pertaining to update were of uniform concern, but none had perfected operational methodologies in this area and only a scant few were able to devote research effort to such initiatives.

6.10 Research and Development

While everyone expressed needs for base funding to conduct research and development, this is not always available. Some found that they must operate entirely as a cost recovery service bureau, even to the point of taking in outside consulting work to make the system pay for its own operating expense. Concurrently, several of the speakers expressed the need for developing university linkages to address such concerns. All looked to universities to integrate GIS training with other disciplinary specializations; several expressed the need to internalize capabilities to conduct training for existing staff.

7. RESEARCH IMPLICATIONS

The following sections attempt to translate the observations just presented into a framework for asking research questions. (There is a correspondence between the subsections given under section 6, and those presented her.)

7.1 Involving Local Government

Are local governments fundamentally different entities than regional or state governments, particularly from a resource management perspective? They generally can not afford the specialized expertise to develop GIS systems on their own, nor frequently can they afford to incur substantial software customization or data conversion expenses. How can we be assured that the components of the NCGIA request for proposals (NSF, 1987) will respond to the needs of *local* institutions? The

software requirements and institutional structures of counties, watershed districts, and the like appear to be very poorly understood considering the sheer number of such units of government (AFT, 1985; Maizel and White, 1987).

7.2 Making GIS Accessible to Day to Day Decisionmakers

Accessibility has both technical and institutional dimensions. The technology is simply "not yet there" when measured in terms of accessibility to local decisionmakers. Porting of GIS functionality to a pc environment (efficient data structures, automated data structuring, spatial analysis capabilities, attention to user interfaces) is certainly crucial. It is not merely reduction of the up-front costs of system development, however, but recognition that grid analyses alone are insufficient, as are parcel based attribute retrieval systems. Existing technology has solved one piece at a time, but has frequently failed to address the multipurpose concept.

Despite the prevalent belief that digital analyses are the coming wave, there seems to be little comprehension of the process of obtaining digital data sets. There is a noticeable absence in the NCGIA discussion of how you capture the stuff (spatial data) in the first place. How is the technology made accessible from both a collection and retrieval standpoint?

We need to struggle with developing methods for evaluating systems (Clapp et al., 1985). Attempts to implement such evaluations (Dueker and Kjerne, 1987) find that few systems have reached a level of maturity sufficient to judge whether they are actually contributing to enhancement of societal well being.

7.3 Understanding Decisionmakers

What inhibits institutions from making the necessary commitments to entering the realm of geoprocessing? Is it liability for the quality of digitally produced data, or for decisions made by combining data from different sources? Is it lack of foresight in budgeting sufficient resources to document, package, distribute, and support datasets and software? If the "priesthood" of experts is still the barrier, what do claims of "user friendliness" really mean? By analogy, Apple opened a large segment of a market willing to adopt computers, yet unwilling to learn the interfaces offered by IBM, DEC, etc. What will the development of such interfaces mean in terms of the local resource manager? We do not know much at all about how such decisions to adopt this technology are made -- why do some take risk, while others shun it (Benveniste, 1977) ? We need more thoughtful case studies of successful applications (see particularly Huxhold, 1984). How often will local and state agencies have to relearn by passing through the same pitfalls so often? There needs to be a better way of communicating the lessons learned.

7.4 Cost Thresholds and Routine Maintenance

We have observed that federal agencies are substantially different from local government in their abilities to adopt new technologies. What is it about incremental methods that needs to be understood, the patching together of disparate, removable pieces? Customizing is inevitable -- new machines, new algorithms, different databases and data structures, will continue to come along. What is needed is a better understanding of long term operating costs in relation to purchase costs. There is a need for rigorous case studies incorporating detailed ongoing cost evaluations (Gurda et al., 1987).

7.5 Communicating Needs for Spatial Control

It is apparent that positioning requirements have frequently been grossly misunderstood by resource

managers. The effects of resource boundary delineations on individual parcels are always present, despite the disparate set of beliefs concerning the importance of various layers in a land information system (Portner and Niemann, 1984). Research is needed to understand different groups' perceptions of the fuzziness of resource boundaries, and also of the precision of cadastral boundaries. Progress toward capturing the decision rules which relate the hierarchy of cadastral objects (monuments, boundaries, parcels) (Dueker and Kjerne, 1987) must be accompanied by efforts to create polygon overlay algorithms which accommodate differential positional certainties with respect to two input coverages.

7.6 Getting Started

Which players within the organizational structure have to be convinced of the benefits of GIS derived analyses, and in what sequence must they be brought up to speed so that they become advocates of the system's development? Providing "something for everyone early on" runs directly in conflict with meticulously building detailed coverages and deriving an overall information management scheme. Evidently, there are tradeoffs between spatial resolution, scope of support, and willingness to start experimenting only to throw away initial efforts, versus adherence to an overall design schema. The general principle that coverages should be automated from the most detailed analog product available may frequently be sacrificed for seemingly overriding needs to complete any coverage as quickly as possible.

7.7 Establishing Custodians

Getting beyond the persistent problems of who automates which layer(s), and how current is the digital data, requires adoption of the custodian concept. Each agency having a legal mandate to collect and maintain a land record should accept responsibility for not only automating that layer in a compatible format, but maintaining the layer over time (Chrisman, 1987). What services can be charged for? And how often must society pay for copying or reusing the same data set? What is the relationship of cost recovery to meeting the social goals of freedom of information acts and open records laws? The need to relate spatial analyses to the property dimension augments needs to think of cost effectiveness, integratability, liability.

7.8 Avoiding Reinvention of the Wheel

How do we get beyond each organization independently inventing a kludge for every new data set or data structure it seeks to incorporate in its analyses? Certainly, better methods of disseminating conversions and work arounds are available; specific software user groups are only the tip. Similarly, the need to develop spatial statistics tools seems to depend more upon conversing about the data, rather than striving to simply derive new indices.

7.9 Testing and Documenting Quality

How do documentation of lineage, tests for positional and attribute accuracy, comprehensiveness, consistency, etc., become incorporated into the standard costs for automating a data layer? How do such efforts contribute to avoiding unnecessary duplication, and thereby contribute to the effective lifetime and utility of the data set? At present, it appears that no one really knows how to manage updates, with the rippling effects such activity has back through the data structures and conveniently discreet portrayal of independent layers. This area is not even reached as a research issue until acceptance has been made of the needs for routine land records maintenance, rather than single purpose project applications.

7.10 Linkages with Universities

Given the constraints of on-line agencies, when and where is extensive innovation to occur? It is apparent that research and development is not adequately funded within local and state government, but the opportunities exist for developing research projects, cooperative agreements, funded sabbaticals, mid-career retraining and short courses, facilitating regional information sharing coalitions. Universities need to embrace extension activities focused on the needs of local and state governments as well as the private sector.

8. SUMMARY

Even though many obstacles remain for the full deployment of GIS technologies, the techniques being developed and demonstrated are moving towards resource management applications which were not conceived as possible using manual or traditional computing techniques. We are beginning to see the tool being used to explore natural resource problems previously not addressable. In the long run, this will be the technology's ultimate contribution.

The NSF request for proposals for a National Center for Geographic Information and Analysis outlines five research categories: spatial theory, spatial statistics, visual perception, artificial intelligence, and economic/social/institutional concerns. Merchant and Ripple (1987), in their foreword to an ASPRS compendium of current GIS papers, state: "We now recognize that institutional, political, and economic considerations may be at least as important as technical issues as we strive to build and utilize geographic information systems." We feel that the research agenda we have presented here, growing out of an examination of eleven natural resource GIS applications, points toward the latter group on the NCGIA list as by far the most important, at least initially. There are many of us who see the societal importance of these technical developments for dealing with complex natural resource management issues.

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A WORKSTATION-BASED GIS FOR LAND ACQUISITION AND PLANNING: THE CONNECTICUT RIVER CASE STUDY

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ABSTRACT

With the advent of 32-bit workstation technology, faster, more accurate, more user-friendly and lower-cost GIS is becoming available. The METLAND (Metropolitan Landscape Planning Model) Research Group at the University of Massachusetts has been developing "MAPLE" (Massachusetts Planning for Landscape and the Environment), a state-of-the-art microcomputer GIS intended for multi-purpose, multi-level landscape/land use planning. This system is currently being tested for its utility to aid in the selection of land for acquisition based on the criteria issued by a state environmental management agency. Results and a system description are described.

1. INTRODUCTION

Land use planning and policy analysis is presently being affected by new technological developments through the use of geographic information systems. Until recently, geographic information systems were dependent on large mainframe computers or mini-computers for data storage, manipulation and analysis. The disadvantages of using GIS have been the high cost of initial acquisition of computer hardware, the requisite space and skilled personnel to maintain and operate the automated system and finally the cost and associated technical problems of converting existing geographic and other data into automated form (i.e. digitizing, scanning, orrelated data conversion).

For these reasons, there have been numerous software packages on microcomputers, that have produced good presentation charts and maps. However, more sophisticated cartographic applications require microcomputers with both powerful processors and high-volume mass-storage devices. To meet this need, GIS have begun to be implemented on machines that are the result of intensive research and development in the computer industry, 32-bit microcomputer workstations.

The METLAND Research Group of the Department of Landscape Architecture and Regional Planning at the University of Massachusetts at Amherst has been developing a state-of-the-art GIS named "MAPLE" on a 32-bit microcomputer intended for multi-purpose, multi-level land use and landscape planning. The objective of MAPLE is to provide a GIS capable of dealing with information at the regional, sub-regional, town and ultimately site scale that will run on inexpensive hardware which will allow the GIS to be integrated into town planning offices for local decision making. To achieve this objective, MAPLE has been applied in such actual situations as growth management and land acquisition problems. One of the test

projects, the Connecticut River Greenway Study, is cited here to exemplify current system capability.

2. GIS REQUIREMENTS IN LOCAL LAND ACQUISITION/PLANNING FOR DECENTRALIZED, PARTICIPATORY DECISIONMAKING

The implications of the microcomputer workstation environment for resource management and local land use planning at the regional to local level are numerous. Local area networking, as well as decentralized, adequate computing facilities for remote or "in-the-field" applications, occasioned by the advent of the workstation technology, bode well for more efficient allocation of ever more closely scrutinized resources to aid in the decision-making process concerning the landscape. The public will, doubtless, be able to become more fully involved in these decisions where their input is warranted.

2.1 Decentralization

One of the profound new phenomena occurring in the United States is the shift from a centralized decision-making process in many aspects of governance (Naisbitt, 1982, p.159). This phenomenon in turn is affecting land use planning by expanding the public's role in the decision-making process. As a result the role of planners is shifting from traditional planning to one which includes education of participants about the planning process and the use of public participation as a means of resolving conflicts between diverse interest groups. The increased reliance on the strategy of decentralization by citizens eager to be more in control of their destiny ensures the vitality of the planning process.

It is expected that decentralization in land use planning will increase, together with debates on what is an appropriate level of decision for various planning problems. As our society becomes better educated and more environmentally conscious, the inefficiencies of large bureaucratic planning become more evident.

2.2 Public Participation

The expansion of the public's role has several important implications for reshaping the planning process and the implementation of land use policy. Clearly, greater participation affords the opportunity for improved land use decisions by making the process more democratic. On the other hand, increased public participation implies a broader range of values and interests than are usually considered in the conventional setting of more centralized planning. It also implies a proliferation of potential conflicts in the attempt to formulate acceptable alternatives. These new conditions require a process which is not only able to handle a much greater amount of data, but also has the ability to generate a larger set of alternatives for evaluation. In this regard, computer technology can play a key role in assisting the planner to work effectively within the participatory framework.

To achieve the goal of truly participatory planning, MAPLE has been developed with the end user in mind. Current GIS, which have resided in the mainframe and minicomputer

environment, are assured of having systems personnel and operators on hand to operate and maintain their hardware systems because of their substantial investment in such equipment. An objective of MAPLE on the workstation is to create a user interface which allows a planner to use the computer as he would other tools. MAPLE's menu-driven command system allows planners to focus their attention on the planning problem at hand rather than on the computer's operating system or the fundamentals of the database management system.

3. APPROACH OF MAPLE

In the summer of 1984, the METLAND research group reoriented the further development of its geographic information system. It was decided that the system should not be a mainframe- and grid-based system as had been the previous system developed in-house by the research group in cooperation with the U.S. Forest Service (Ferris and Fabos, 1974). This strategy was adopted for two reasons. First, the increased availability of digital spatial data predicated an increased use of such material; consequently it was decided that the computing environment for handling spatial data must be scaled down from the mainframe in order to proliferate the use of such data and related geographic information systems among landscape planners and others. Concurrent developments in the computer technology field provided the answer. A suitable, lower cost, powerful environment, in which the research group could develop a prototype system, was found in the form of the 32-bit engineering workstation. Second, it was decided that the previous grid-based system had several drawbacks. Among these were 1) the fact that the feature boundaries of the natural phenomena it was modeling were not being accurately duplicated; 2) the data structure required extensive computing time and storage that would make its implementation in the scaled-down computing environment difficult; and 3) the data structure used was not as flexible for manipulation and analysis purposes as other methods the state-of-the-art demonstrated were feasible to conceive of and implement. It was decided that in-house capabilities existed to develop the computer software needed to improve the system in these areas. The principal investigator and research group members decided to adopt a boundary-based view of the data. This new approach and the new hardware environment necessitated a new system design.

3.1 Hardware

The MAPLE system was initially designed and developed on a SUN Microsystems, Inc., SUN-2/120 with a MC 68010 CPU, 16 MByte of virtual address space per process, 4.0 MBytes of main memory, a "mouse" pointing device, high resolution display and bit-mapped graphics controller, a color graphic controller with medium resolution display, a 1/4" streaming tape backup, a floating point processor board, and an expansion pedestal containing a 130(formatted) MByte 8-inch Winchester disk; a Summagraphics Microgrid 36"x 48" digitizing tablet; and an ACT II color ink jet printer. MAPLE is implemented in C with dynamic memory allocation.

3.2 Software

The MAPLE system consists of three major programs: a data entry or digitizing program called "draw"; a data base creation and data structuring program called "build"; and a data base extraction and manipulation program called "view". All three programs share a similarly-styled user interface in which mouse-selectable graphic menus control program operation. Text entry is from the keyboard. The common interface across all programs establishes easy-to-learn conventions, providing a productive work environment. All operations of the latter two programs can be journaled, and the resulting, editable scripts can be run in batch mode. A summary of the three programs are as follows.

"draw"

'draw' is the data entry or digitizing program of the system. The program provides a means of digitally recording the geographic coordinates of analog spatial information through the use of a digitizing tablet. The program features visual editing, windowing, and attribute label placement. The program also allows for previously digitized maps to be displayed as a reference when a new map is digitized. The system uses only three objects: edges, vertices, and labels. Digitizing can be performed either in so-called "arc-node" or "spaghetti" fashion. Coordinates are stored in binary format for data compaction purposes; however, the program has the capability to write these coordinates out to an ASCII file in format compatible with popular commercial GIS.

"build"

'build' is the data base creation and data structuring program of the system. The program provides a means of defining the various parameters of a spatial data base: its spatial extent, i.e., what area the data base will include; its structure, i.e., what discrete layers of information the data base will contain and the relationship between or among those layers; its associated thematic components, i.e., data files in any ASCII format can be related to the spatial information. Finally, the program reads digitized information, compresses the data, establishes the connectivity of that information, and inserts the information into the appropriate layer of the data base.

"view"

'view' is the data base extraction and manipulation program of the system. Users can retrieve a previously defined data base and extract a spatially-bound 'plate' of their choosing from any or all layers of information within the data base to constitute a 'sample'. This sample can be manipulated to provide a final map through the agency of several selectable, combinable operations, e.g., overlay, buffer generation, attribute reclassification, and logical operations on tabular data. Maps can be interactively colored, legends and other cartographic information attached, and the map can be plotted on an ink-jet printer or large format pen plotter if available.

4. THE CONNECTICUT RIVER CASE STUDY

By applying MAPLE to an actual landscape planning procedure, the GIS capabilities of MAPLE are hereby demonstrated.

4.1 Statement of Problem

The Massachusetts Department of Environmental Management (DEM) was allocated an initial $2 million appropriation for land acquisition along the Connecticut River Valley. As part of a cooperative agreement between the Department and the Department of Landscape Architecture and Regional Planning at the University of Massachusetts at Amherst, a study was conducted to aid DEM in determining crucial land parcels and the most optimal public land uses for acquisition. A part of Reach 2 (Mt. Toby U.S.G.S. quadrangle) in the Connecticut River was chosen for this study to accomplish the following two purposes: (1) to test MAPLE, and (2) to solve the real landscape planning problems by using MAPLE.

Reach 2 has been under tremendous growth pressures both on the river banks and on the water. DEM needed to identify significant resources to protect or develop under this growth pressure. These are recreational resources, agricultural lands, and wildlife habitats resources. The main focus is on the land acquisition issue and the key question is which land parcel has higher acquisition priority in terms of the development and protection of the critical resources in the study area.

4.2 Methodology

To solve this problem, two more methods developed from previous METLAND studies were combined into the MAPLE GIS: (1) Assessment techniques for the three resources, and (2) a mathematical (optimization) model to assign the most effective land uses to each land parcel. The detailed procedures are as follows.

In order to have the suitability maps needed for the assessment of the three important resources, nine layers of data parameters were selected from the METLAND assessment procedures: (1) river, (2) site boundary, (3) land use/ land cover, (4) land ownership, (5) roads, (6) soils, (7) slope, (8) existing recreation, and (9) rare and endangered wildlife habitats. Each layer was digitized in the data entry component of MAPLE. A database was constructed of these data using the second component of the system. The data were then manipulated using the third component of the system.

In summary, the necessary data parameters for the assessment of the three resources were digitized, structured, and manipulated in the MAPLE system. Suitability maps for those resources were generated. However, since the objective of this study is to determine crucial land parcels for acquisition, the result from each suitability map is not sufficient especially when the land uses derived from the critical resources co-occur and conflicting with land parcel boundaries. To determine the most compatible land uses parcel by parcel and to prioritize the parcels for acquisition, an optimization model (Painho, Fabos, Gross, 1987) was developed and applied in this study.

<u>Application of Optimization Model</u>

The usefulness of the Optimization Model is that it can deal with the important features of this study; (1) to be multiobjective/ multicriteria; (2) to handle landownership (parcels) as individual units, i.e., as integers. The way found to achieve this twofold feature is to take a

linear program and make it integer by means of an appropriate constraint set. Finally, to be able to obtain multiobjective capability, a suitability objective function, similar to an utility function, was developed.

The final output of the Optimization Model is a list of what parcel groups were assigned to what land uses and this result can be gained by maximizing the objective function subject to the given constraints in an optimization package. As a result, conflicting land uses were ruled out in the optimization process and each parcel can have the most effectively compatible land uses. For instance, if a parcel has three compatible land uses, then it could be said that the parcel has a higher priority than a parcel which has two compatible land uses. Finally, parcels with the highest priority were chosen in this way and recommended for acquisition.

This approach is highly responsive to the growing complexity of landscape problems facing planners today. It is exemplary of the level of sophistication necessary to address the multiobjective nature of landscape planning's state of the art. MAPLE contributed to the Optimization Model by providing all of the spatial data for the Model (i.e. soil map superimposed by land parcel lines). The automation of the calculation process and the full integration of an optimization package in the MAPLE system is one of the prominent items on the METLAND research agenda for completely computer-assisted landscape planning.

5. CONCLUSION

The use of the MAPLE system for the case study proved to be extremely timely at this critical stage of its development. This rigorous testing of its capabilities in the field demonstrated the benefits of its basic design and the flexibility of its three program functions.

Many researchers, including the METLAND research team, are convinced that GIS development in the coming years will move to the workstation environment. Successful experiments in the 32-bit workstation environment and the price/performance values have begun to prompt commercial vendors to orient their products to take advantage of this technology. Additionally, the easy acquisition of digital data from automated scanners or remote sensing devices will offer unprecedented opportunities for landscape and land use planning.

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RESEARCH FOR VALIDATING CADASTRAL DATA

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ABSTRACT

There are numerous research issues to be addressed in regard to validating the cadastral data contained within geographic information systems. One research area concerns the formulation of surveying standards and cadastral mapping standards which will remain valid and relevant regardless of rapid advances in technology and which will remain constant as one moves from a multipurpose cadastre under the laws of one state to the next.

Another important research area concerns efficient means for collecting and conclusively validating cadastral data. Scenarios for expert system boundary surveyors and expert system cadastral mappers are suggested. The paper suggests that interdisciplinary approaches are needed to make significant research advances on cadastral issues.

1. Background

Leading experts in the technical development of geographic information systems (GIS) now recognize that the current lack of understanding of political, social, and institutional influences is a major impediment to GIS system design advances. (1,2,3) The tough issues, temporarily swept under the rug in the pursuance of specific technical developments, are now re-emerging to

challenge the validity of the technical advancements made to date. (1) One of these tough issues involves the current inability to create spatially accurate, legally supportive, and operationally efficient land ownership data bases.

It is generally acknowledged that GIS technologies will not come into full fruition in the U.S. as multipurpose useful tools for society until physical and measurable attributes of the land are able to be securely tied to legal ownership rights in the land. There are so many other interests which are so inextricably tied to ownership interests that the cadastral layer of information has from the very outset been recognized as a crucial element of any widely applicable GIS. (4) Queries relating to ownership, encumbrances, encroachments, parcel size, value, zoning, use, resource distribution, taxes, conveyancing history, financing, building restrictions, and many others inevitably depend on the accuracy, completeness, and accessibility of the cadastral information in the GIS.

It is interesting to note that not a single public real property conveyancing system (i.e. deed records system) in the U.S. has fully embraced GIS technology. Only a handful of courthouses have computerized the indexing of their deed recording systems. No jurisdiction has yet to seriously consider relying on a computerized system as the official legal record of property ownership (i.e. title to property) or the official record of ownership line location. Some technical barriers exist. However, through observation of operating courthouse systems and past initiatives to automate them, it is readily evident that non-resolved technical issues create far less a barrier than the non-resolved legal, institutional, and economic issues. These social issues are only beginning to be addressed in a land information system context. Realistic technical solutions are not achievable without substantial direction and support from the results of social research.

The public real property records in virtually every U.S. jurisdiction exist in a very primitive state. The records are kept manually in books or on microfilm and are accessed by grantor and grantee indexes or sometimes by tract indexes. Searches of the records by lawyers and others are accomplished by manually developing a chain of title and then examining each discovered instrument in the appropriate book or microfilm file. (5)

Ownership and security in land always have been considered sacred private rights in the United States. Therefore, stewards of the public real property records such as judges, registers of deeds, and local governmental officials are loathe to accept anything short of "almost perfect" technical solutions before allowing automated land records keeping systems to supplant current manual systems. Hence, the tragedy. Without experience with the needs and constraints of actual operating public systems, near-perfect technical solutions will never be achieved. Without near-perfect technical solutions, public real property systems remain under static archaic conditions.

Because modernization of official real property record systems needs to occur in a step-by-step process, automated real property records systems are evolving not in the offices of register of deeds and recorders but in the offices of tax assessors, local planners, and other governmental offices who are able to utilize automated systems which initially provide many but not all of their data needs. As these automated systems duplicate and improve upon the functions carried out by the official real property recorder's office the numerous technical problems are addressed and solved. Eventually, both an automated and a manual real property recording system co-exist. The two systems test the validity of each other. Issues and concerns in regard to access, security, reliability, reproducibility, and numerous other pragmatic legal and social considerations are next addressed and resolved. At some point the reliability and efficiency of the automated system is proven to be superior to that of the manual

system and the automated system becomes the official legal record of title. This scenario has been completed in several foreign countries and is beginning to be witnessed in the U.S. However, automating existing real property titling systems in the U.S. is only a small portion and the easier portion of the long term solution to tieing legal interests in land to their spatial locations.

2. ROLE OF THE LEGAL SYSTEM

When a GIS is called upon to answer questions in order to resolve actual real property conflicts, the validity of data in the system is called into question. The U.S. legal system provides the framework for testing the validity of data in any GIS. When the legal system is invoked in regard to land data, real property ownership rights inevitably and inexorably come into issue. Without complete and legally supportive cadastral information in the GIS, all other data in the GIS immediately becomes suspect and open to challenges based on validity and reliability.

Across the nation, GIS data bases are being compiled at phenomenal rates and at considerable expense. Yet in regard to legal support and broadbased multipurpose capabilities, all of these GIS stand on foundations of clay. The systems hold together for limited purposes but when substantial legal demands are placed on the GISs the systems collapse.

Solutions in providing strong legal foundations for GIS are not simple. The often repeated attempts at digitizing inconclusive cadastral data and cross referencing of title information are stop gaps at best. Methods for supplying comprehensive and officially sanctioned cadastral data need to be extensively investigated. Much of the problem appears to lie with the underlying data. It is not so much that appropriate GIS technologies must be developed as that

methods of collection and formats for land-related data should be adapted. To alter the legal system's official and customary methods of collection and formatting, a thorough understanding must be acquired of why data in its current format and collection mode meets the needs of the legal system. With an understanding of the legal systems needs and constraints, the legal system no longer exists as a barrier to GIS advancements. In fact, the legal system provides researchers with the tools and raw materials to create a strong and durable social, economic, and institutional foundation for all GIS building.

3. SPECIFIC CADASTRAL RESEARCH TOPICS

Cadastral information consists of primarily two major forms; ownership/title information and boundary location information. Extensively used and relatively reliable public depositories exist for title information but not for boundary location information. Some information on boundaries exists in public records in the form of metes and bounds descriptions on deeds, in the form of tax parcel sketches, or in the form of recorded surveys and subdivision maps. However, the most relevant and up-to-date evidence on the locations of parcel boundaries is typically found in the private files of surveyors, banks, title insurance companies, and others involved in the transfer and development of real property. The survey maps and accompanying documentation held by these people typically provide the best available information on the physical dimensions and relative positions of a property owner's rights. However, because most property surveys are seldom recorded and are contained only in private files, boundary line information is far more difficult to accumulate for incorporation into a multipurpose GIS than is title information.

In addition, even if the surveys in private files were readily accessible, property surveys are seldom tied to a general spatial reference framework. This shortcoming is a

primary factor in causing the most valuable spatial information from a legal perspective to be the least likely to be incorporated into a GIS.

In an attempt to address the lack of consistent and efficiently useable boundary information, research should begin along several fronts. One research area concerns formulation of surveying standards and cadastral mapping standards which will remain valid and relevant regardless of rapid advances in technology and which will remain constant as one moves from a multipurpose cadastre under the laws of one state to the next.

With recent advances in surveying field and computational techniques, the technical standards for boundary surveys of the individual states are rapidly becoming out-of-date and are inapplicable even now in controlling the quality of many boundary surveys. A comprehensively prepared model law for boundary survey technical standards would substantially aid individual states in upgrading their laws while promoting uniformity in such standards among the states. Such a model law might require the public filing of all property boundary surveys as is currently required in at leas a few jurisdictions. Federal and state programs to financially aid local communities in upgrading or automating their official real property record systems might require the model law be enacted by the state or local community prior to the distribution of funds to the community.

Model laws are often developed by the legal profession and others to address problems caused by the non-uniformity of laws in the various states. Input is gained from both practitioners and academicians nationwide to ensure the model law will be both workable and comprehensive. Statutory language is developed which may be adopted with little or no change by any or all of the individual states. Such model laws are only advisory to the states. Past experience has shown, however, that the development of such

models has a positive impact on the lawmakers of individual states. Thus, model laws have been extremely effective in streamlining and simplifying practices and procedures relating to many legal topics throughout the U.S. (6)

The development of a model law which would provide for the forms and quality of cadastral information necessary for appropriate GIS development would require research leadership and input from legal scholars, GIS designers and developers, surveying measurement scholars, and practitioners in the several related real property-based disciplines. This diverse group of related experts could be brought together in a mutually productive research environment if centered around concerted and well defined research goals.

The model law scenario is but a single scenario in how consistent and comprehensive boundary information might be made publicly and readily accessible to those who could productively use it in establishing the much needed cadastral foundations for GIS development. There are numerous similar techniques which the GIS community might use to impact current legal, professional, and governmental institutions so as to promote a fertile environment for GIs advancements. The most promising should be exposed and pursued.

Model laws and uniform standards are fine as first steps and as instruments for institutional change. However, significant scientific advancements also need to be made before efficient collection and integration of cadastral information into GIS environments is possible. At least one researcher has suggested that work should begin on developing expert systems which carry out the functions of a cadastral cartographer. (7) Another has suggested that a first step should be development of an expert system that compares legal descriptions in a given area, deduces the topological structure among the adjacent parcels, and detects major discrepancies between the bounds of the parcels. (Frank) These proposals are attempts at

automating the decision-making paths followed in the process of evaluating inconclusive boundary data.

For instance, an expert system cadastral cartographer would likely incorporate the rules of thumb currently used by tax mappers when resolving gaps and overlaps exposed by deed descriptions, subdivision maps, survey maps, highway plats, and other boundary information accessible from the public record. The expert system would incorporate the rules of thumb used in resolving incomplete information and resolving conflicting information from different sources from different periods of time.

Though such proposals are perhaps first steps in dealing with cadastral data in an automated environment, these proposals fail to address the basic issue of legal integrity of the data. They fail to address shortcomings in the underlying data. They are attempts at technological fixes.

The most expedient solutions for dealing with this complex body of spatially related and legally dependent information will not be solely technological in nature. A combination and intertwining of technological solutions and institutional solutions is required. For instance, if the previously discussed model law scenario was carried out to address some of the data complexities caused by institutional factors, an expert system for cadastral information might deal with incorporating the best available evidence for the locations of property lines as opposed to dealing with ambiguities and conflicts large sets of inconclusive data.

An adequate and competent interpretation of a legal description frequently requires physical inspection of the property for relevant evidence and requires measurements between the evidence found. The field evidence is compared to the record evidence for the parcel and adjoining parcels. Using customs of the profession, knowledge of

standards of practice, and presumptions developed in the case law for resolving conflicts, the surveyor or attorney arrives at their best opinion as to where they believe the lines would be located if the conflicts were fully adjudicated in a court of law. It is the results of these professional opinions (i.e. boundary survey maps and accompanying documentation of the reasoning process) which typically provide the best available evidence as to where the boundaries lie.

An expert system which would test the results of the surveyors or attorneys boundary line opinions would be extremely useful in arriving at highly consistent and legally supportable cadastral frameworks for GIS. The primary use of the proposed expert system would be as an expert consultant. After a land surveyor or lawyer interprets the evidence himself and draws his conclusion concerning the appropriate location for the property lines, he would than consult the expert system to get the expert system's "opinion". The expert system might expose issues and reasoning which the land surveyor or lawyer overlooked. With this additional information the land surveyor could re-evaluate whether his initial conclusions are still the most reasonable. In the interpretation of legal evidence there are no "true" answers floating around waiting to be found. Thus, it is virtually impossible under our current U.S. legal system to develop a system which will always arrive at the "correct" answer. However, an expert system which arrives at "reasonable" or even "most reasonable" answers is certainly a possibility.

After consistent and comprehensive legal validation of cadastral information becomes routinely acheiveable, technical problems will still remain in integrating cadastral data with other forms of data in a multipurpose GIS. Though the boundary components of cadastral information may be graphically represented and spatially manipulated, much of the legally relevant cadastral data is conventionally communicated in words rather than in symbols

or dimensions. Keeping this data updated and efficiently merged with raster and vector manipulation techniques is another entire area of research consideration.

CONCLUSIONS

Social and institutional research shows promise of providing GIS researchers with the cadastral validation techniques which will allow technical research to proceed with greater direction and utility. With legal ownership rights in land securely tied to the physical and measurable attributes of the land, the automated GIS becomes an extremely powerful social tool. Although research advancements in the area of institutional and legal issues are difficult to gauge and although such issues are less glamorous than the "high tech" issues, GIS technical advancements perhaps have advanced to the level of sophistication where concerted social research is now an appropriate next level of concerted effort.

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NEEDS OF A LARGE SCALE CADASTRE AT THE COUNTY LEVEL

by Dr. Harry Emrick, Jeffco Elected Surveyor

Abstract: Small Scale Mapping with the associated Cadastre is in good shape down to the 7 1/2' quad level. The county and especially urban jurisdictions urgently need data of "engineering" and "geodetic" accuracies for the ultimate base layer of the Multi-Purpose Cadastre (MPC).

Jefferson County has, since the early 1970's, been in the forefront of both the establishment of geodetic control and the implementation of computerized parcel mapping, therefore, it is obvious to me that the two are interrelated. As more agencies and institutions become accustomed to automated mapping, the need for more definition to the GIS will ultimately drive the concomitant requirement for more accurate surveys.

Even though only one unique geodetic (or geographic) coordinate can be attributed to a property (parcel) corner, the professional surveyors that utilize the recognized methodology can justify several locations for the same coordinate, depending upon which geodetic tie the surveys are based on, if any. As you know, several consecutive measurements between the same points seldom if ever agree, thus we have the requirement for the statistical techniques of "adjustment computations" and the computational techniques of "numerical analysis" in order to come up with a "unique" solution. Most measurement systems common to the surveying and mapping industry to include "Global Positioning" and "Automated Cartography" use statistical techniques. Of course, statistical techniques do not provide us with the only unique solution but only with a "best fit" solution in accordance with the quality of the data used. We need to reduce the "error ellipse" associated with any solution to a justifiable minimum.

Jefferson County was surveyed as part of the Public Land Survey System, however, much of the county is mountainous and the determination of the location of the original or replacement PLSS monuments is often very difficult. In both the mountains and the plains of Jefferson County, many of the monuments have been removed or mysteriously disappeared in other ways. The PLSS data base needs modernization in the non-federal as well as the federal lands. This modernization should include the reestablishment of the missing monuments as well as placing coordinates on each section corner. This will allow any surveyor to be within three-quarters mile of a locatable monument with a unique set of coordinates.

Various methodology exists for the densification of existing sparse networks such as: Aerial Photogrammetry, Global Positioning (GPS) and Inertial Positioning Systems (IPS). The accuracy of these techniques usually vary from 1 to 25 centimeters.

The "trickle down" theory of the Federal activities in providing assistance to local government seems to be more difficult to understand when considering the explosion of information/ technology available to all levels of government and private industry. We believe that the detail work needs to be performed at the city and county level of government at the appropriate "larger scale" of 1"=200'/1"=400'/1"=600' etc. and then aggregated for state level use at 1:24,000/1:50,000 scales and then aggregated again for the Federal/Worldwide users. Implicit in this concept is the inter-availability of information between these and other layers of government.

In Jefferson County we are digitizing the county using every available data source including: USGS DLG, Census Bureau DIME File, Base Map hand digitization et. al. and then connecting this information to the local surveyor's monument and plat records in a logical fashion.

At this time there is no integrated educational program in Denver/Colorado to provide the impetus, as well as the work study student assistance, to carry out our county program much further. It appears as though we are being surrounded by states with educational programs and no pilot county, whereas, we have the pilot county with great potential for research and productivity, but as of this writing there is little state government or university incentives to continue. We are relying strictly on an internal effort and stretching the limited internal resources.

In summary, at the county level we require a mini surveying and mapping structure utilizing the techniques and tools developed co-operatively with the Federal surveying and mapping agencies. (Note: Colorado has no official focal point in the State System for Surveying, Mapping, GIS cooperation-Jefferson County through mapping director Billie Swenson has been acting as the ad hoc agent of the state to get the work done.)

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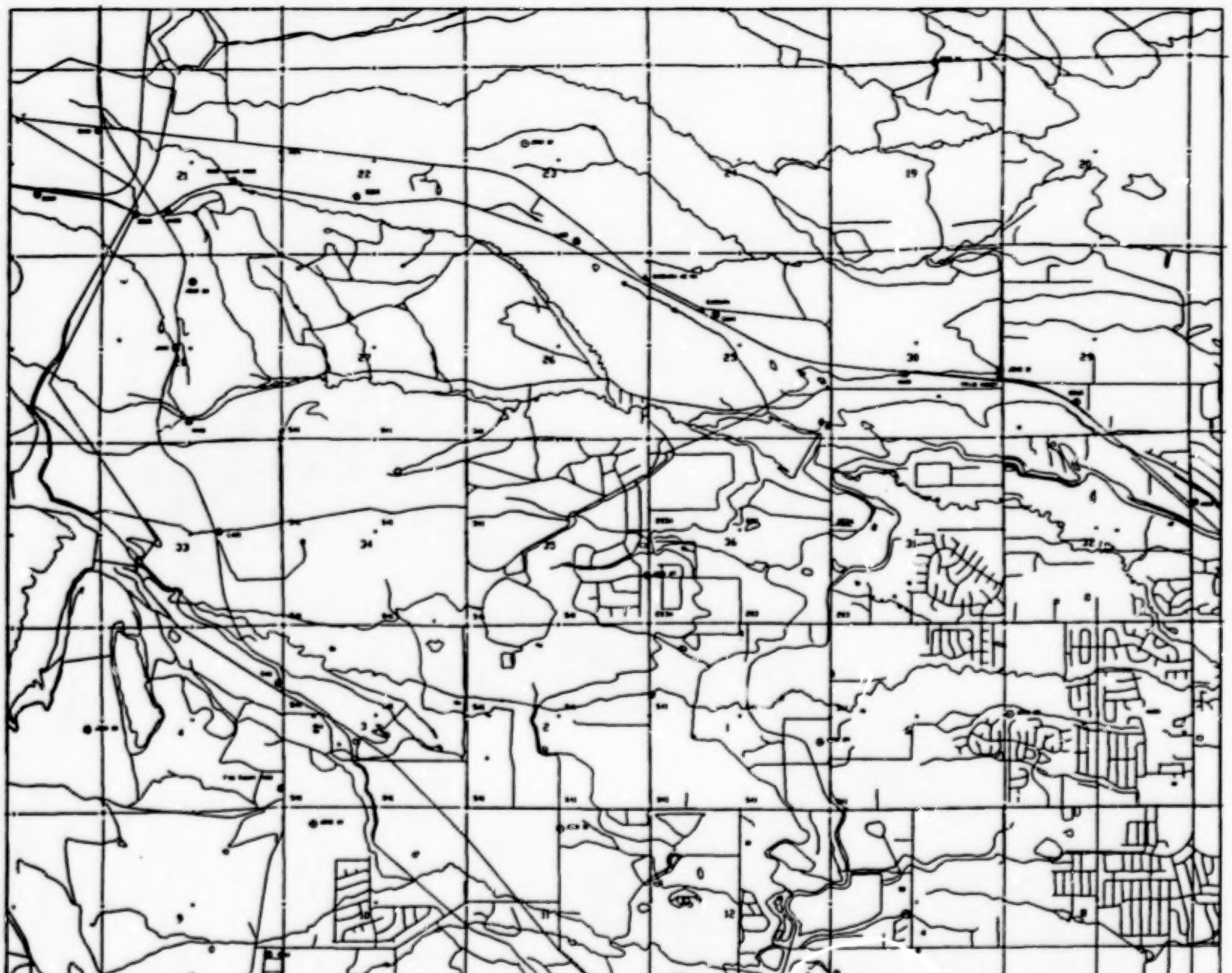
Golden, CO 7.5' Quad



Scale 1" = 2000'   USGS 1:24000 DLG FILE Displayed and plotted by Autocad
DLG to Autocad conversion software by JCMD

This drawing represents a composite of several data sources

From the USGS DLG, Blue = hydrography, Green = pipelines and transmission lines
Red = railroads, Black = roads
From JCMD Databases, Red = public land survey, III-365 *subdivision plats*
From NGS Databases, Red = horizontal and vertical geodetic control

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GEOGRAPHIC INFORMATION SYSTEMS PROGRAMMING IN ADA*

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ABSTRACT

The crisis associated with programming geographic information systems and other geographic applications software is very similar to the software crisis facing the United States Department of Defense. Ada, the programming language developed for the Department of Defense, has proven to be a language in which geographers can effectively learn good software design and programming concepts. Ada has also proven to be a language equal or superior to Fortran for communicating algorithms and writing geographic applications software traditionally written in Fortran.

1. INTRODUCTION

Geographic application programs are often very large, are usually developed by large programming teams, must be adaptable to a variety of hardware configurations, and have lifespans so long that they must survive numerous upgrades and modifications while still accommodating data developed under earlier versions or alternative programs. These factors have created a geographic applications software crisis (Wellar, 1985; Taylor, 1985). Furthermore, because of the size and complexity of geographic applications software, most of this software is now written by highly skilled programmers who too often lack knowledge of both the fundamentals of good cartographic design and the basic problems and methods of geographic data handling (Monmonier, 1982).

An identical crisis became evident in the United States Department of Defense in the 1970's (Downes and Goldsack, 1984 ;Booch, 1987). Programs to operate embedded systems have exactly the same characteristics and problems attributed to geographic application programs in the preceding paragraph.

Ada is a proprietary computer programming language developed for the United States Department of Defense specifically for the purpose of overcoming these problems of embedded system

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* Ada is a registered trademark of the U.S. Government, Ada Joint Programs Office.

programming. Furthermore, it is a powerful and flexible general purpose language which strictly enforces software design principles (Shumate, 1984). It utilizes many modern features of computer hardware, which Fortran, the traditional language of geographic applications, is ill-equipped to use.

Therefore, the authors asked two questions. First, can people who are not programming experts learn enough of the language to use it for minor programming tasks and to participate effectively as members of programming teams developing large geographic applications packages and thereby enhance geographic quality of the software? Second, can Ada be used easily as a basic geographic applications programming language? The balance of this paper is devoted to a discussion of experience in answering these two questions.

2. LEARNING ADA

Ada has generally been presented as a large, complex language which can be studied meaningfully only after one has mastered both "simple" languages like Pascal and Fortran and extensive software development principles (Cohen, 1986). Preference is given to Pascal because it is the teaching language of choice in most American university computer science departments and, after all, both Pascal and Ada share Algol as a common ancestor. Ichbiah, the Ada development team leader, suggests that Pascal-to-Ada conversion programs should be relatively straightforward to write (Shammas, 1985) and RR Software supplies such a program with their Janus/Ada subset compilers.

On the other hand, Texel (1986) has presented Ada as a first language and Ichbiah's Alsys Corporation has produced a computer-aided instructional package entitled **"You Know Fortran, Ada is Simple."** The concept underlying this instructional package is especially important in geographic applications because virtually all available algorithms are in the form of published Fortran programs.

Operating on the principles that Ada can be a first programming language and that learning any programming language is like learning any other foreign language, the senior author has taught Ada to students whose backgrounds ranged from no prior programming experience to thirty credit hours of computer science course work. Most students had prior programming training in either Pascal or Fortran, although one had training only in Basic. Student performance reflected no significant difference as a function of prior programming knowledge. However, if any group of students had an advantage, it was those students who knew Fortran. The reasons for this appear to be that the Ada package concept is more like

Fortran library and subroutine concepts than it is like any feature of Pascal and that there tends to be a confusion factor between Ada and Pascal. This confusion stems from the fact that some identical or nearly identical expressions have subtly or even substantially different meanings.

Obviously, these students did not master the full scope of the Ada language in one semester. However, they learned enough to write modest geographic applications programs, such as screen oriented raster map production and basic statistical analysis programs. Parenthetically, it might be noted that one student, who had no prior programming experience, has gone on to write, unassisted, a program to calculate soil infiltration rates for use in his thesis.

The key reason that Ada can be learned as a first language and that useful programs can be produced so quickly is that the language embodies a new programming concept. Unlike Fortran, which uses a linear data flow programming concept, and Pascal, which relies on top-down programming, Ada impels use of a bottom-up programming design. The central Ada concept of reusable packages means that individual programs can be reduced to a size and simplicity which allow completion of these packages as real, functioning entities. Larger programs can then be fabricated by appropriate assembly of these component packages.

This concept requires suitable software engineering oversight to ensure that all appropriate packages are completed in good order. The authors have found that a project director can quickly produce the necessary package specifications for use by all team members, allowing each to proceed more or less independently. Thus, each learner can begin almost immediately to produce useful packages and independent programs, which provide an effective educational reward system.

3. GEOGRAPHIC APPLICATION PROGRAMMING

The bottom-up programming of packages also forms the key to using Ada in larger applications programs, such as geographic information systems. Such systems must perform a wide variety of tasks, most of which are quite simple on an individual basis. The complexity of a GIS lies in the numbers of different major activities which the system may be required to perform and the number of minor activities associated with each major task.

As noted earlier, virtually all geographic application software, from SYMAP to MOSS, has been written in Fortran and virtually all available algorithms have been presented in the form of Fortran programs. The series Computer Applications from the University of Nottingham Geography Department and Computer Contributions from the

Kansas State Geological Survey serve as prime examples of these resources. Relatively few algorithms are available as either flowcharts, pseudocode, or programs in other languages.

Since the authors are firm believers in the concept of not reinventing the wheel whenever possible, it seemed desirable to test the feasibility of using some of these algorithms as a basis for new Ada programs. The results were, to say the least, surprising. Fortran programs can be translated almost line for line into Ada. The result is a poor Ada program from the standpoint of code size, execution efficiency, and style. But, the Ada program compiles more compactly than the Fortran program and it executes correctly. The authors do not consider this to be a good programming procedure but note the point primarily because we have obtained several public domain Pascal programs which cannot be converted into Ada on anything approaching a line-by-line basis.

The proper use of existing Fortran programs is to provide a pool of ideas for solving geographic problems. Extraction of the methods used in these programs and redesign of these methods into effective Ada programs proves to be a relatively straightforward task which results in compact programs which execute quite efficiently.

Five capabilities of Ada have proven most useful to date in writing geographic applications software. (1) Ada programs, partly because of the length of allowed variable names and partly because of the elaborate form of many statements, read very much like cryptic English. If good indentation and other style features are used, programs are quite easy to read although programmers habituated to truly cryptic languages like C may find Ada source code rather cumbersome. (2) Dynamic allocation of arrays greatly facilitates geographic applications programming by solving one of the most vexing problems of Fortran programmers, that is, the difficulty of anticipating future execution requirements. (3) When properly employed, exception handlers are powerful tools for dealing with both I/O and execution errors and special execution cases. (4) Looping may be achieved in a variety of ways and can directly resolve several of the problems which have traditionally plagued Fortran programmers. (5) Input/output is a fairly complex part of the language but provides great flexibility in free-format and fixed-format modes, allowing use of newer format approaches while preserving the best of the past.

The authors have so far encountered only two major defects of the language standard. One is failure to require implementation of the full (256 element) ASCII code set. This severely limits direct graphics output on many video monitors and dot matrix printers. The other is failure to directly implement non-integer loops, although this can be circumvented. One other problem is that, despite the abundance of text and reference books on the language, few have been written with the practical programmer in mind. One

of our early programming errors was finally solved when we happened across a sample block of code in Cohen (1986). Cohen offered no explanation nor have we found any other source which explains why the coding must be done in that particular way. In another example, explanations of exception handlers leave to programmers the task of figuring out what their capabilities and proper implementation are with far too little guidance.

4. SUMMARY

The world of geographic computer applications has changed enormously in the twenty years since the Harvard Laboratory for Computer Graphics and Spatial Analysis released SYMAP. Geographers are unlikely to do much of their own programming in the future, but must be able to both understand the programming and maintain sufficient control of the software design process to ensure that geographically valid programs are available.

The highly readable nature of Ada programs, coupled with the power and flexibility of the language, make Ada extremely attractive as a language in which geographers can learn programming concepts, communicate future algorithms, and interact meaningfully with professional programmers. Given that Fortran has been the programming language of geographic applications and that Fortran, despite its numerous modifications, is an increasingly obsolescent language, we endorse Ichbiah's view that Ada is a very effective alternative to Fortran (Shammas, 1985).

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AN OVERVIEW OF THE ARMY GIS RESEARCH PROGRAM

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ABSTRACT

The U.S. Army Engineer Topographic Laboratories (USAETL) geographic information systems (GIS) research program seeks to define GIS requirements for operational use in the 1990's and beyond, and to develop advanced GIS processing techniques that will facilitate detailed, near-real-time update and revision and terrain product generation. USAETL has initiated two new work units in the GIS technology base research program. The projects follow an earlier work unit, the Terrain Analyst Work Station (TAWS), which successfully demonstrated microcomputer-based GIS technology in field and Army garrison environments. From evaluations of TAWS demonstrations and development activities, researchers are proposing baseline Army GIS requirements and are working at developing corresponding performance standards. The functional requirements are the framework for the new work units, the Army GIS Evaluation (AGE) and the Soldier-to-GIS Interface Research (S-GIR). AGE is a study to test and evaluate off-the-shelf GIS with respect to meeting current and anticipated Army requirements for the management and manipulation of digital terrain data (DTD). S-GIR is a developmental effort which will study and prepare a dynamic design for a specialized direct manipulation user interface. S-GIR is based on the critical need for a sophisticated and highly interactive user interface for Army GIS applications. S-GIR is intended to assist designers in developing a sophisticated shell or 'front-end' for GIS modules which will be selected (based on AGE study results) for use in a prototype advanced Army GIS.

1. BACKGROUND

The U.S. Army Corps of Engineers - Engineer Topographic Laboratories (USAETL) have utilized geographic information systems (GIS) for the last decade to develop terrain data models and prepare prototype terrain analysis products, to study data structures and exchange formats, and to support the research and development of both hard and softcopy data capture systems. With the advent of small, powerful and low cost microcomputers, researchers were able to bring GIS technology out to the field to determine its applicability in supporting tactical terrain analysis. The Terrain Analyst Work Station (TAWS) was the first such exploratory developmental effort

that utilized 32-bit engineering work station technology to host a GIS. TAWS also featured a hardcopy data capture and mensuration subsystem, and ancillary terrain modeling and environmental effects data base systems. Six proof-of-concept TAWS demonstrations from 1984 to 1987 have shown that GIS can successfully support Army planning and tactical operations in field and garrison settings.

Engineering development of the first GIS-based system to be deployed in the field for tactical applications is underway. The system, called the Digital Topographic Support System (DTSS), will be deployed at Division, Corps and Theater echelons. Initial deployment will consist of three systems. Upon successful development and fielding of the first engineering models, up to fifty-five systems may be procured. The DTSS is designed to have a twenty year lifespan, with planned hardware and software upgrades to incorporate technological advances. The DTSS will initially support processing of primarily 1:50,000 scale Tactical Terrain Data (TTD) which will include the corresponding resolution Digital Terrain Elevation Data (DTED).

The DTSS represents the first of probably several GIS-based systems designed to address the specialized tactical and planning mapping support requirements of the engineering, terrain analysis, logistics, intelligence and combat operations functions of the Army. Currently, other Army terrain data users at echelons below Division, in garrison activities and working on other laboratory and system development efforts, are not included in the planned DTSS program. Many of these users are looking for ways to address their immediate and near-term terrain data processing requirements by seeking to implement GIS capabilities. Additionally, some Army terrain units awaiting the early 1990's deployment of DTSS are looking for low cost interim or supplementary off-the-shelf GIS solutions which will familiarize them with the technology and permit them to initiate digital data base creation activities prior to DTSS deployment. USAETL, acting as the Army clearinghouse for GIS technology, has initiated the Army GIS Evaluation (AGE) in response to this need. There is concern about the possible impacts of an ad-hoc proliferation of GIS within the Army, particularly now that the technology is widely available on the commercial market. The concerns include whether the stated capabilities of systems can actually meet specific Army functional requirements, how data quality standards can be ensured, and how Army consumers can ascertain that they are selecting a cost-effective solution.

2. AGE PURPOSE

AGE is intended to permit applications and systems scientists to perform in-depth studies of off-the-shelf GIS products (both commercial and public), to provide a structured forum for vendors and

developers to showcase their products to potential Army consumers, and to provide an information clearinghouse for all Army components interested in obtaining near-term GIS capabilities. Additionally, AGE will provide the DTSS program with GIS technology updates and will report and recommend innovative and successful GIS implementations which may be incorporated into the system.

AGE is utilizing the analyzed data gathered at the TAWS demonstrations to implement and test some of the recommended functional capabilities derived from these results. The AGE study is also intended to promote competition in GIS acquisition activities by emplacing a work unit that will examine numerous systems to assess developments and breakthroughs in the rapidly advancing GIS field.

There are a number of philosophical premises that led to the AGE project. The first premise is that the field of GIS is changing too fast for the USAETL GIS research program to "lock" into one particular system or technology. The "luxury" of "playing the field" is one not afforded to most operational or developmental environments, but it is a well-suited and essential function for an activity dedicated to GIS research. There is a tendency amongst Federal GIS users today to become dedicated proponents of one of a few particular systems. Unfortunately, only these few of the many systems and software products available have been exercised in depth, not affording an adequate opportunity for some vendors or developers to showcase their systems. This can result in creating a market environment which stifles rather than fosters innovation.

Given the rapid progress in advancing the state-of-the-art in GIS, another AGE project adage is to look for systems which economically can be warranted for a five year or less system lifecycle. This should facilitate the process of upgrading and/or replacing system components and consequently should mitigate the problem of supporting systems that are technologically obsolete and costly to maintain.

From successful results of the Terrain Analyst Work Station (TAWS) program, USAETL researchers concluded that advanced microcomputer technology adequately met Army GIS requirements. Therefore, AGE will focus exclusively on GIS products which operate on supermicrocomputers (engineering work stations) or microcomputers (advanced personal computers). Since the Army GIS requirements can be satisfactorily addressed using microcomputer technology, there is no need to examine products which operate only on larger, more expensive systems. Also, by utilizing as small a system as technologically feasible, the AGE goal of maintaining a short product lifecycle can be economically realized. Preliminary study indicates that personal, desk top microcomputers may have limited utility in addressing the extent of processing requirements and the density of data needed for most military applications; therefore the bulk of the evaluation will be committed to examining engineering work station

GIS solutions. However, advances in desk top or lap top (highly portable and compact) microcomputers are of great interest to the researchers. When these sized and priced systems can host GIS that satisfactorily address Army geographic data processing requirements, all echelons will be able to derive the benefits of computer assisted terrain analysis.

It is probable that several systems may partially meet the Army GIS requirements, but there may not be any one system which optimally addresses all the requirements. If this turns out to be the case, the AGE program will evaluate whether there should be an amalgam of several system components combined into a single, multipurpose work station or the use of several, dedicated GIS work stations to address the total GIS functional requirements.

The AGE concept was introduced in late fiscal year 1987. The Army GIS Evaluation is a multi-year effort, but the actual system tests will be confined to a two year period that will be initiated in the second half of fiscal year 1988. This way, systems selected for study at the onset of the project can be evaluated in roughly the same technological context as those selected later in the project. The project may be renewed in two years, but it is expected that the field will have evolved to the level that those systems selected for the second study cannot be evaluated using the same framework as the initial study. The short evaluation period also ensures that results are disseminated to Army customers as rapidly as possible.

3. S-GIR PURPOSE

The TAWS demonstration results indicate that the most critical Army GIS design area is the soldier-to-GIS interface. Therefore, the USAETL GIS research program will focus its development activities on the design of a specialized user interface. This work unit, called Soldier-to-GIS Interface Research (S-GIR), will create and study several user interface designs on a dedicated rapid prototyping system. The results of the experimental designs will be used to develop an advanced user interface to serve as a front-end for GIS applications modules.

S-GIR will utilize commercially available, low cost rapid prototyping software to explore different approaches to developing the user interface design. The designs will be keyed to preliminary performance standards derived from Army GIS functional requirements. The designs will implement, as much as possible, direct manipulation interface technologies. That is, they will employ a highly interactive, graphical interface that presents to the user all alternative courses of action and permits the user to execute (or, if needed, reverse), in a single step, the intended operation. S-GIR will utilize multiple process windows, pop-up and pull-down menus,

graphic icons to depict commands or functions, and comprehensive "help" functions.

The S-GIR study goal is to strive for simplicity of operations without limiting the GIS functional capabilities. The underlying philosophical premise to S-GIR is that the applications modules should conform to the way that the user perceives and expects to interact with the system (and not vice versa).

S-GIR is a multi-year program. During the first phase, the experimental designs will be developed on the dedicated prototyping system. The prototyping system will not contain working GIS modules; it will just serve as a dynamic design mock-up. Each mock-up iteration will be evaluated by researchers and soldier users. The resulting analysis will be used to prepare a specification for a soldier-to-GIS subsystem. The second phase of S-GIR is to develop a methodology in which to implement the specified design as a front end for operational GIS applications modules. At this phase in the study, the AGE results will be utilized to select the best suited system(s) to work in conjunction with the new interface subsystem. Most probably, the design will be implemented using a standard windowing protocol which can be implemented on an engineering work station. After the interface has been implemented with working GIS software, a suite of computer-aided instruction (CAI) modules will be developed to work with the system. Long range S-GIR goals include the development of an "intelligent interface" with an expert system terrain analyst's toolbox to assist and support the process of terrain analysis. The terrain analyst's toolbox will employ adaptive interface techniques to provide appropriate levels of guidance and cues to the users which will be based on the types of inputs received.

4. REQUIREMENTS ASSESSMENT

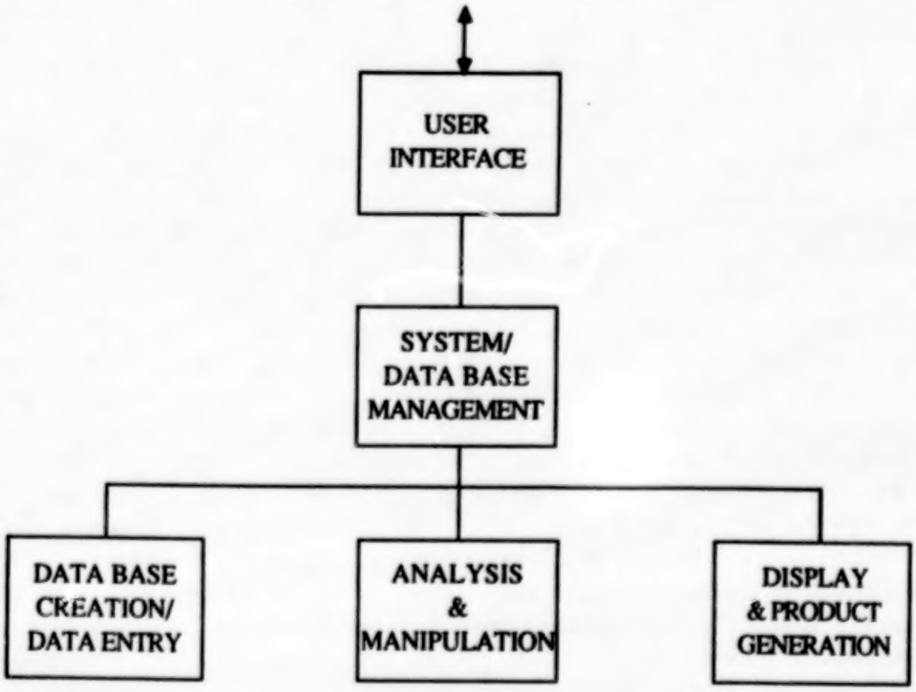
The first phases of the S-GIR and AGE projects involved developing baseline functional requirements. The requirements are analyzed and used to derive system performance standards. The requirements and their corresponding performance standards serve as a paradigm for which benchmark tests can be formulated.

A simple model was devised to develop a conceptual framework and provide a structure for studying GIS functions. The model, depicted in Figure 1, divides geographic information systems into five functional subsystems: the user interface, system / data base management, data base creation / data entry, analysis and manipulation, and display and product generation.

The user interface is the subsystem through which all human interaction with the applications modules are made. Although the S-

GIR project entails developing a specialized user interface, this subsystem of each off-the-shelf GIS will still be assessed in the AGE project. The user interface subsystems will be evaluated with respect to both the effectiveness of the interface as it functions with the other components of the GIS, and the potential for modifying or building a shell around it (such as the one to be developed through the S-GIR project).

Figure 1. GIS Functional Model



There are some targeted performance standards for the user interface subsystem. The user interface should facilitate the process of learning to operate the GIS, and it should provide the user with an efficient and effective means to invoke the full intended functionality of the system. By the end of the first day of use, the Army terrain analysts should be able to, at a minimum, accomplish a tangible task or set of functions using the GIS. The soldiers should be able to learn to use the full functionality of the GIS in about two weeks. Mastery of GIS skills is recommended to be obtained in about two months or less. The system should motivate and expedite terrain analysis processing by both soldiers who have acquired the expertise on the system and novice users. It should not encumber the performance of skilled users nor hinder the learning process of new users. The user interface should permit the user to have flexibility in accessing and manipulating the data base, but it must also utilize protective measures to ensure the integrity of the data.

Certain techniques may be employed to enable a system to meet these

performance standards. These include (but are not limited to) providing effective documentation and meaningful on-line error messages, providing data base 'locks' and 'keys' to protect the integrity of the data base, supporting reversibility of operations, and offering the user an array of choices to select from (rather than relying on the user to first formulate the possible alternatives, select the best suited one, and then recall the proper procedure for invoking that function). The user interface should be designed so that each system function has a direct relationship with each logical step in the terrain analysis process.

The system / data base management component of a GIS establishes what types of data can be stored in the system, how they are stored, and how all the applications modules access the data. The major functional component of this subsystem is the querying or retrieval capability. The GIS should be able to manage both vector and raster formatted data. The data bases may be either aggregated or divided into thematic overlays. (Tactical terrain data may be distributed in an aggregated form and most probably will be the major source of digital terrain data bases for the Army.) The Army GIS will typically manage three types of overlays: factor overlays, functional overlays and composite overlays. Factor overlays are the standard thematic overlays found in the current hardcopy DMA terrain analysis products called the Tactical (1:50,000 scale) and Planning (1:250,000 scale) Terrain Analysis Data Bases (TTADB and PTADB). They are: soils and surface materials, slope, drainage, transportation and lines of communication, vegetation, and obstacles. Functional overlays are special purpose or application specific thematic layers. Some examples of functional overlays are an overlay depicting troop or supply locations that might be needed for a logistics application, cloud cover or precipitation data that might be needed for a meteorological model, or detailed water resources and geological overlays that might be needed for an engineering application. Composite overlays are the byproduct of a query or analytical operation. A composite overlay is a derived data layer from one or more factor or functional overlays. An example is a composite overlay derived from a query to the vegetation and soils and slope factors which have met a particular set of criteria and which may be used as one component of a cross country mobility model.

Some of the specific requirements for the system / data base management capabilities for the Army GIS are outlined in the following chart.

SYSTEM / DATA BASE MANAGEMENT CAPABILITIES

Data Base Structure
* World wide capability
* Map sheet independent
* Variable sized manuscripts accommodated
* Thematic overlay handling
* Aggregated data sets handling
* Meta-data handling
* Topological and non-topological capability
* Multiple data structures (raster types, vector types)
* X-Y and X-Y-Z data handling
* Functional, factor and composite overlays
* Multiple attributes and microdescriptors
* Attribute tags at all spatial entity levels
* Edge matching

Querying Capability
* Any / all attribute combinations
* Feedback on estimated time to complete
* Arithmetic operands
* Data type specific or global
* Within or across thematic layers
* Conditional (if / then) queries
* Queries saved as procedural macros
* Queries global or on active window or user-specified area

Data Management
* Standard and special purpose attribute assignments
* Look up tables for all data base codes
* Data dictionary capability for all layers, products
* Lock keys for data base protection
* Save or delete overlays in part or as a whole
* Data base status reports: quality, contents
* Sort, redefine data base
* Data base indexing
* Standard (default) and nonstandard file naming convention
* Browse or previewing capability
* Attribute editing interactively or batch update
* Modification, deletion or addition of graphic elements
* Quality assurance checks

System management
* Transaction log
* Maintainability, supportability
* Links to other systems (data capture, modeling, etc.)
* Ability to enhance / modify
* Password protection
* Operating system independence

The data base creation / data entry subsystem supports the method in which the terrain data are brought into the system. It is limited by the types of data which can be stored and controlled via the data base management subsystem, or by data which can be converted to a usable form via the analysis and manipulation subsystem. Editing of digital data is a function of this subsystem, as is topological structuring and verification. Both the graphic and attribute components of the data must be able to be edited both at the time and after they are digitized. Certain threshold values for connecting line segments, weeding or thinning extraneous points should be available as default operations but should also be modifiable by the

operator. Other data quality checks are also components of this portion of the GIS. Generally, terrain data can be brought into a GIS via digitizing (hardcopy) cartographic or photographic products or via reading in and utilizing digital (softcopy) image or geographic data. Some GIS support data base creation as an integral component of the system while others provide the ability to import data from external data capture systems. Although the terms are sometimes used synonymously, data entry refers to the importing of digital data that has been created externally, while data base creation refers to the process of generating a digital data base locally.

The Army GIS must be able to utilize standard (and proposed standard) Defense Mapping Agency (DMA) digital products, such as Digital Terrain Elevation Data (DTED) and Tactical Terrain Data (TTD). Additionally, the systems must be able to import data bases or digital products (symbolized composite overlays) created on other terrain analysis systems, such as the Digital Topographic Support System (DTSS) or from dedicated data capture or image exploitation systems.

The only economically feasible manner in which to utilize data created externally on different systems is to employ standard exchange formats. The GIS researchers are, therefore, closely following the efforts within the Defense and Federal mapping communities to establish standards and specifications for the interchange of digital geographic data. The systems selected for evaluation will be assessed with regard to their ability to be modified, if needed, to input and utilize standard formatted data. When data exchange standards are implemented, a mandatory requirement for an Army GIS will be to throughput in these specified formats.

The scarcity of available digital terrain analysis data bases is the most serious obstacle impeding the widespread use of GIS in tactical and planning military applications. Therefore, the data entry / data base creation subsystem plays a particularly crucial role in a GIS. Advances in data capture technologies, such as scanning digitizers with character reading capabilities and advanced image analysis and automatic feature recognition systems will greatly increase the utility of GIS. If a GIS supports a local data base creation capability, it should be able to support digitizing of hardcopy terrain products or images in as rapid and efficient a manner as possible. Attribute tagging of the graphical features, and clean up and editing of digitized graphics are typically so time consuming that, in many cases, the time dedicated to building an initial data base overshadows the time savings realized in performing the data analysis and product generation on a GIS. A revolutionary breakthrough in the use of GIS will occur if quantum leaps are made in data capture technologies. Otherwise, GIS usage will increase in a more gradual manner as the holdings of digital data archives

increase through steady, time intensive efforts to construct the data bases.

The analysis and manipulation subsystem forms the nucleus of the GIS. This capability, working in concert with the data base management subsystem, distinguishes a GIS from other computer-based mapping systems. The analysis and manipulation subsystem supports data base transformations, classifications, statistical analysis, proximity analysis and mensuration functions, and arithmetic, algebraic and geometric manipulations.

Data base transformations are a broad class of operations which include: map projection or coordinate transformations, data structure reformatting, logical or physical file structure reformatting, attribute conversions, geometric corrections or registration adjustments either between data base layers within an area or between adjacent areas, unit of measurement conversions between metric, imperial or U.S. conventions, and valid scaling operations.

Location identification is a major GIS mensuration operation required for Army use. This includes: location identification by place name or description, by coordinate input or Milgrid identification, or graphically via a pointing device. Other mensuration functions include computing distance (path or straight line), length, centroid, area, volume, perimeter of features or of specified parameters. Required proximity functions include buffer operations and spatial neighborhood analysis, which is the ability to query and conduct GIS operations based on adjacency or "nearness" as a criteria.

The statistical analyses should accommodate cases of both certainty and uncertainty. The statistical functions were not extensively utilized on TAWS; however, as GIS are utilized more extensively and in a more sophisticated manner, these capabilities will most probably be required to support modeling of various phenomena. Classification functions include grouping, sorting, deleting and merging data entities based on both quantitative and qualitative criteria. The mathematic functions include arithmetic manipulation on numeric attributes of the data, geometric adjustments such as rotating, stretching and warping, interpolation, contouring and generalization, and the algebraic operations working in conjunction with the data base management querying capability.

The analysis and manipulation subsystem should support the generation and execution of specific models or simulations. These include mobility, physical distribution, environmental effects, intervisibility, terrain analysis and engineering models. Some special purpose functions such as elevation modeling, adjustments to horizontal or vertical exaggeration, profiling, shaded relief and aspect mapping, and the ability to merge thematic overlays with

elevation or image data are useful in some military applications.

The display and product generation subsystem supports the creation of graphical or text output which are either routed to display devices to depict activities occurring in the GIS, or as products which are routed to either display devices for analysis, to digital storage media for use on other computer based systems or to hardcopy output devices. The two major components of this subsystem are the cartographic assignment and report writing capabilities, and the display and output device control functions.

The GIS should be able to generate hardcopy products in both standard military map formats and in project specific formats. This includes use of symbols, colors, labels; legend and title placement; and the ability to place add-ons and insets on the map product. The softcopy products may be used by other GIS based systems, by command and control systems, or as electronic map background display. They must be output in standard digital product formats as needed.

The display and output device control functions determine how products are developed and on what types of hardware on which they can be displayed or output. The Army system should be able to create a display window or zoom into an active map display based on utilizing a pointing device, identifying corner coordinates or center coordinates with a specified radius, or via a spatial entity (state, region, or other designated place name). The process of routing graphic data from the display screen to an output device should be simplified through an efficient link between the user interface and the display subsystem. The entire process of cartographic assignment can be very lengthy, particularly if the system is sensitive to differences in display and plotting devices and consequently requires the user to repeat several processes to transfer products from one device to another. For example, if a system requires that the operator re-assign or modify a product on a display screen prior to plotting on a hardcopy output device, this is time consuming and frustrating to the operator. The ideal procedure for a GIS would be to automatically adjust and modify the product as needed when a change in output device is made. Much of the initial cartographic assignment should be done automatically if the user is generating a standard product. But to ensure an effective and aesthetic presentation, the user should be able to interactively adjust the plot or report as needed, preferably via a direct manipulation interface.

5. PROGRAM STATUS

A small GIS laboratory has been established at USAETL to conduct the AGE and S-GIR projects. The phase one S-GIR system will be designed in-house with prototyping support from Colorado State University.

AGE will be an in-house effort accomplished with the cooperation of the GIS vendors selected for the study. GIS vendors have been solicited for AGE via the "R&D Sources Sought" column of The Commerce Business Daily, and through professional meetings such as this one. Interested vendors and developers will be asked to fill out a questionnaire regarding the general capabilities of their systems, the notable features of the GIS, the required hardware configuration(s), the costs proposed for the study, the costs of the system should it be procured, the accessibility of the software source code or import and export routines, the support provided for the study and the support required by the government. The research team will select several systems in the desk top / personal microcomputer class and several systems in the advanced engineering work station class based on the questionnaire results. Vendors that are selected for the study will be expected to loan their systems to the government at no charge but will be reimbursed for non-recoverable expenses such as documentation and training costs, the cost of equipment transport and insurance. Systems will be loaned to USAETL for approximately six months.

Researchers are currently preparing six types of test data sets for the AGE. The first data set will be an aggregated data set to simulate the handling of the Tactical Terrain Data because it may be distributed in an aggregated form. The second test case will be an actual hard copy data base which will be typical of the standard terrain factor overlays. Some functional overlays may be added to test certain data base management and analytical capabilities. The third type of data set will actually be several small samples of data from an area in various map projections. The fourth type of data set will include data from various regions of the world. The fifth type data set will include various scale data in variable sized manuscripts and a built up or urban area inset. The sixth type of data set will include various geometric test cases to investigate the limits and accuracies of the systems.

The preliminary work leading to AGE and S-GIR was the development of baseline Army GIS functional requirements derived from the TAWS demonstration results and from discussions with USAETL researchers involved in specifying digital terrain data (DTD) content and format for the Army. The functional requirements are a dynamic document and will be revised as more GIS demonstrations and evaluations are performed. Scenarios for exercising the capabilities of the systems are currently being formulated. USAETL research personnel will utilize the test data sets in the operational scenarios to conduct quantitative and qualitative benchmarking of the performance of the AGE systems. The actual tests are scheduled to commence in the spring of 1988.

ACKNOWLEDGEMENTS

The support and cooperation of Mr. Homer Babcock, Chief, Geographic Information Systems Branch, for reviewing this report and providing the day-to-day administration of the USAETL GIS work units during the six months that I was on developmental work details outside of the laboratory is greatly appreciated. I also thank Mr. Victor Gonzales for his assistance in developing the baseline functional requirements, Ms. Carla Ennis for her assistance in preparing the presentation materials and in selecting and gathering sample data sets for the benchmark tests, Mr. Fred Muhlenberg for his efforts in formulating test cases for the analysis and manipulation subsystem, and the other folks in the GIS branch for holding down the fort and preparing for the GIS evaluation.

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AIRLAND BATTLEFIELD ENVIRONMENT (ALBE) TACTICAL DECISION AID (TDA) DEMONSTRATION PROGRAM

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ABSTRACT

Terrain and weather affect combat operations more significantly than any other physical factors on the battlefield. Historically, field commanders have not had the capability to fully exploit battlefield environmental effects for tactical advantage. The Corps of Engineers has initiated the ALBE program to develop and evaluate Tactical Decision Aid (TDA) software and products. The TDA's, when implemented on developmental systems, will provide the Army with an operational capability to assess and exploit battlefield environmental effects as a force multiplier in combat operations. A government developed Geographic Information System (GIS) will provide the databases that the TDA software will access to generate products. A development strategy has been devised that involves assembling an ALBE Testbed, installing the GIS and TDA software, conducting field demonstrations and evaluations, and transferring the TDA software to various target systems currently in the life cycle development process. This innovative approach will facilitate fielding of ALBE software and products, and will provide battlefield commanders and their staff with the ability to better exploit the combined effects of terrain and environment in the decision-making process.

1. INTRODUCTION

Terrain and weather environmental effects are arguably the most significant and limiting factors for a commander in combat operations. However, collection of this data is a slow process, and in most cases environmental intelligence products cannot be generated with the speed needed to support continuous operations. Therefore, tactical decisions have to be made with limited knowledge of the battlefield environment, even though such factors can be detrimental to the performance of today's high technology Army systems. In addressing this problem, the Army is initiating development and fielding of advanced technology systems such as the All Source Analysis System (ASAS), Maneuver Control System (MCS), Digital Topographic Support System (DTSS) and Integrated Meteorological System (IMETS). These systems will

provide the capability to acquire and process intelligence, maneuver, terrain and environmental information, respectively, in an efficient and timely manner. In addition, the Corps of Engineers, tasked with providing a synergistic approach to the efficient assessment and exploitation of environmental battlefield effects, has instituted the AirLand Battlefield Environment (ALBE) initiative.

ALBE will facilitate the acquisition, integration, assessment and exploitation of terrain, weather and other environmental information through a government owned Geographic Information System (GIS). The GIS will provide for the implementation of Tactical Decision Aids (TDA's). Two major goals of the ALBE initiative are:

provide Army material acquisition, training and doctrine activities with the capability of assessing and exploiting realistic battlefield environmental effects.

provide the Army in the field with the capability to assess and exploit battlefield environmental effects for tactical advantage.

This paper will address the ALBE TDA Technology Demonstration program, one of the Army's top twenty technology demonstrations, and the GIS which provides the environment for generating these TDA products. This program is designed to provide a mechanism for demonstrating and evaluating TDA products developed under the Corps of Engineers' tech base efforts and to facilitate transfer of these products to Field Army systems. The TDA Technology Demonstration program will address goal two of the ALBE initiative. The primary objectives of the program are:

develop and refine GIS software to support TDA product generation.

develop and refine TDA software and develop the methodology to provide TDA software and products to Army operational units.

demonstrate the use of advanced sensor systems for collection of near-real-time battlefield environmental data and use of the data in the generation of TDA products.

obtain the test data necessary to support integration of ALBE TDA software and products on soon-to-be fielded Army systems.

The development strategy for the TDA Technology Demonstration program is to assemble an ALBE Testbed (ATB, which will be used as the vehicle for conducting the ALBE Demonstrations, implement

and integrate the TDA software into the ATB, conduct a series of demonstrations and evaluations to gather data and develop methodologies for transitioning the TDA products to Army fielded systems, and transfer of the TDA software to materiel developers of the Army fielded systems.

2. BACKGROUND

The ALBE TDA Technology Demonstration program is being conducted under the auspices of the Corps of Engineers Directorate of Research and Development with the work being performed cooperatively be Corps of Engineers (COE) and Army Materiel Command (AMC) laboratories. Participating laboratories include the Corps of Engineers'; Cold Regions Research and Engineering Laboratory (CRREL), the Construction Engineering Research Laboratory (CERL), the Waterways Experiment Station (WES), and the Engineer Topographic Laboratories; along with AMC's Atmospheric Sciences Laboratory (ASL). The TRADOC proponent for the ALBE Technology Demonstration program is the U.S. Army Intelligence School (UASICS). The Army Development and Employment Agency (ADEA) will support the ALBE effort by: facilitating the coordination necessary to execute the field demonstrations and evaluations with the appropriate FORSCOM and TRADOC element, and assisting in the integration of ALBE software and products into the Army's SIGMA C I architecture. The U.S. Army 9th Infantry Division will also support the TDA Technology Demonstration program by providing troops to operate and evaluate the ALBE software during Command Post Exercises and Field Training Exercises.

3. ALBE Testbed (ATS)

The ATB is designed for maximum flexibility (both hardware and software) to satisfy TDA developer requirements and provide a suitable demonstration vehicle which can function in a realistic battlefield environment. The ATB hardware consists of two ruggedized MicroVAX central processing units (CPUs). One CPU will be dedicated to terrain applications while the other is dedicated to weather applications (Figures 1 and 2). Both units use multiple hard disks, tape drives, graphic and alphanumeric input and output devices, and communication devices. The Terrain CPU will include an X/Y Digitizing input device and a CCD Mapping Camera. The Weather CPU will include an environmental sensor suite to detect surface and upper air meteorological data. Both CPUs will communicate with each other and with other related computer systems.

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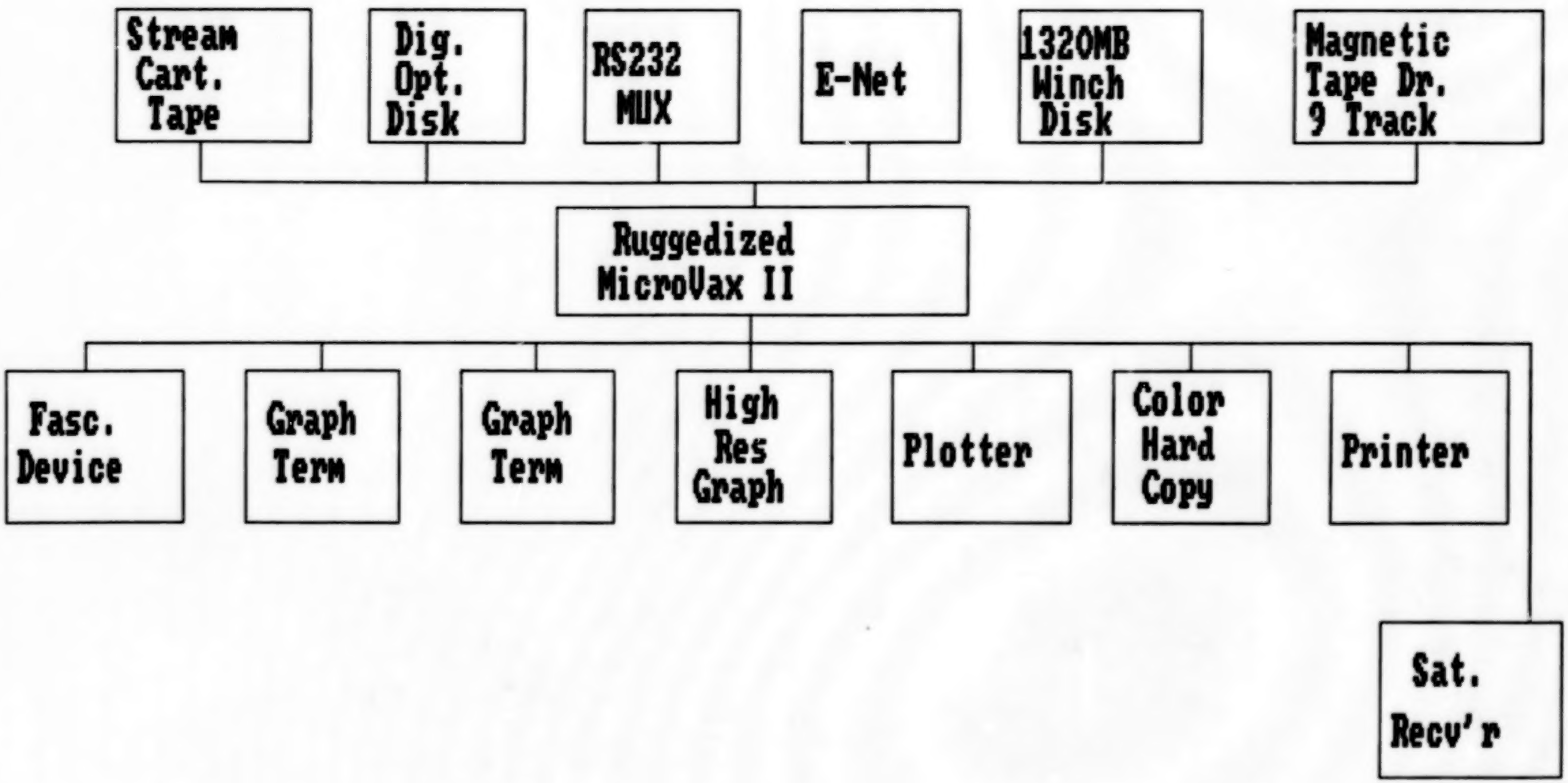

FIGURE 1:

Block Diagram of the Weather-Intensive ATS Processor

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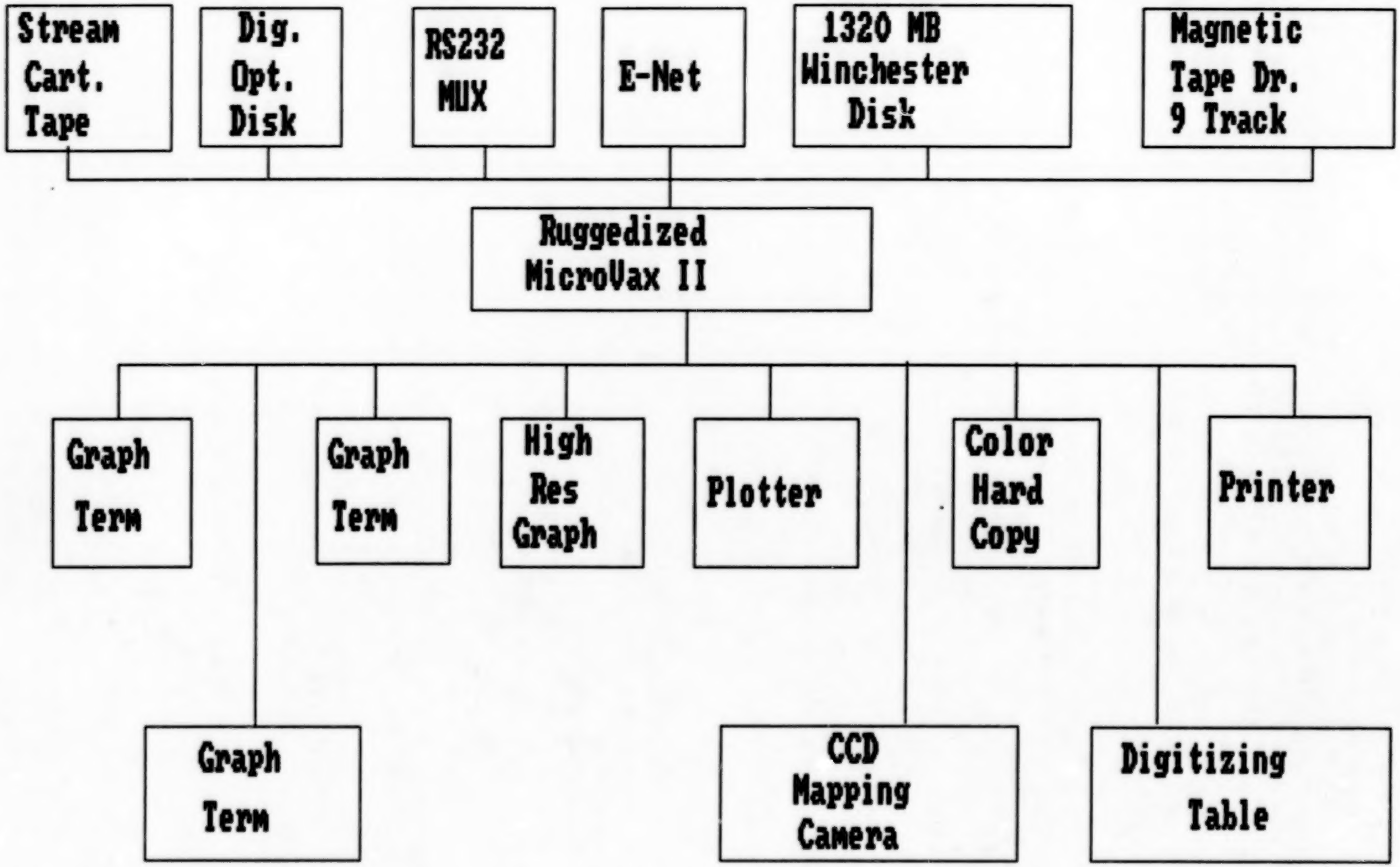

FIGURE 2:

Block Diagram of the Terrain Intensive ATS Processor

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In addition to the GIS and TDA software, the ATB will consist of: operating system software (Virtual Memory System - MicroVMS), Data Base Management System (DBMS) software, GKS graphics libraries, and user interface software. These components of the ATB system software architecture will be integrated into a cohesive software package where TDA software exploitation of terrain and weather data can occur. The ATB software will also contain language compilers for FORTRAN 77. PASCAL, C, and ADA. Figure 3 illustrates the software architecture.

The ATB will be installed into an Integrated Command Post (ICP) type shelters which are being mounted on Commercial Utility Cargo Vehicles (CUCVs) for transport during the ALBE demonstrations and evaluations. This configuration will be accomplished in October 1987. Acquisition and integration of the ATB hardware and implementation of the system software is being accomplished under contract by Battelle Pacific Northwest Laboratories (PNL).

4. GEOGRAPHIC INFORMATION SYSTEM (GIS)

4.1 Overview

The ALBE Geographic Information System (GIS) consists of several software packages which enable an analyst to create, extract, store, manipulate, and display digital terrain data. This data, which can be displayed in hard and soft copy and raster and vector forms, is the basis for the production of Tactical Decision Aids. The ALBE GIS consists of the following public domain software; the Analytical Mapping System (AMS) which allows for the digitization of data, the Map Overlay Statistical System (MOSS) which offers statistical analysis of vector data, and the Map Analysis and Processing Subsystem (MAPS) which allows for the conversion of vector to raster data and the subsequent statistical analysis. In addition to the aforementioned basic software, the GIS includes a map projection package which allows the user to select from twenty unique map projections.

AMS, MOSS, and MAPS have been in use with a variety of computers and operating systems and as a result there is widespread knowledge, throughout the geographic information system's community, of their capabilities. This paper will not be focused on those capabilities, but will elaborate on the exploitation of those capabilities for the TDA development and enhancements to the system which are unique to the ALBE GIS. Significant developments to AMS, MOSS, and MAPS include: the conversion from the HP-UNIX environment to a 32-bit word, MicroVMS environment,

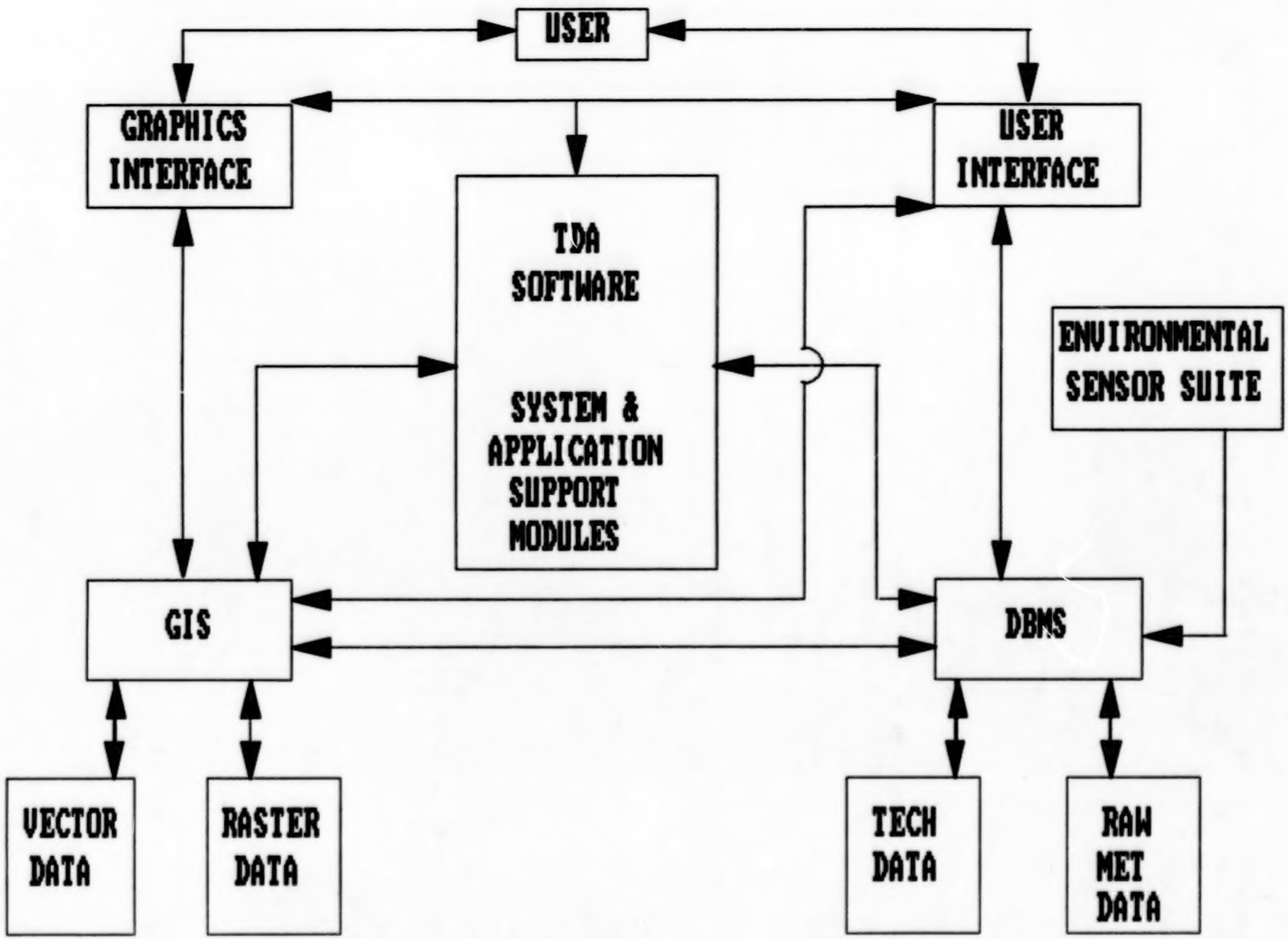

FIGURE 3: ALBE SYSTEM SOFTWARE ARCHITECHTURE

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the replacement of DI-3000 with Battelle's Passthrough routines (GKS calls and Rastertek 1/10 driver), and the remodelling of the database directory structure (Figure 4). This work was performed by DBA Systems, Inc. DBA is also nearing completion on several software modules that will be integrated into the GIS. These enhancements include; Arcnode Overlay processing capability in AMS, Raster to Vector conversion, and Standard Linear Format (SLF) import and export capabilities. The Cartographic Output System (COS) is scheduled to be converted to operate with the ALBE GIS within a year. COS will enhance the system by providing cartographic quality output.

4.2 Analytical Mapping System (AMS)

Figure 5 illustrates the flow of data processing through the various software modules of the GIS. The AMS is a software package that permits the user to create a digital, geographic database. Features of AMS include: graphic display, editing, softcopy, data/integrity verification, database storage and retrieval, simultaneous user procedures, and twenty standard map projections. The AMS software is menu driven, with several layers of menus which allow the user to select options that will exploit the capabilities. AMS contains a photogrammetric subsystem which supports data extraction from various imagery sources and has been used in some ETL programs; however, there are no plans at this time to integrate this software for use in the ALBE GIS.

Once user accounts, a project area, and themes (soils, vegetation, slope, etc.) have been established, the digital database can be created. The source of data for the digital databases has been Defense Mapping Agency TTADB's (1:50000). The ALBE GIS uses an in-house attribute coding scheme to represent the features that are digitized from these TTADB's. At this point, the data exists in binary, AMS format. As a digitizing job is in process, the data is kept in arc-node format, vectors and the attributes associated with them are stored in the system. Once the job is databased, this arc-node information is retained, as well as polygon information. AMS maintains a list of polygons and the vectors and attributes that compose them. If a segment is shared by two polygons, the coordinates for that common segment are stored once, with each polygon having a pointer to that stored segment.

Alternative data sources will be available when the Standard Linear Format (SLF) Import/Export routines are integrated into the GIS. Data created in AMS on any other computer system can be transfered to the ALBE GIS via SLF and all attributes will be

ALBE GIS DATABASE DIRECTORY STRUCTURE

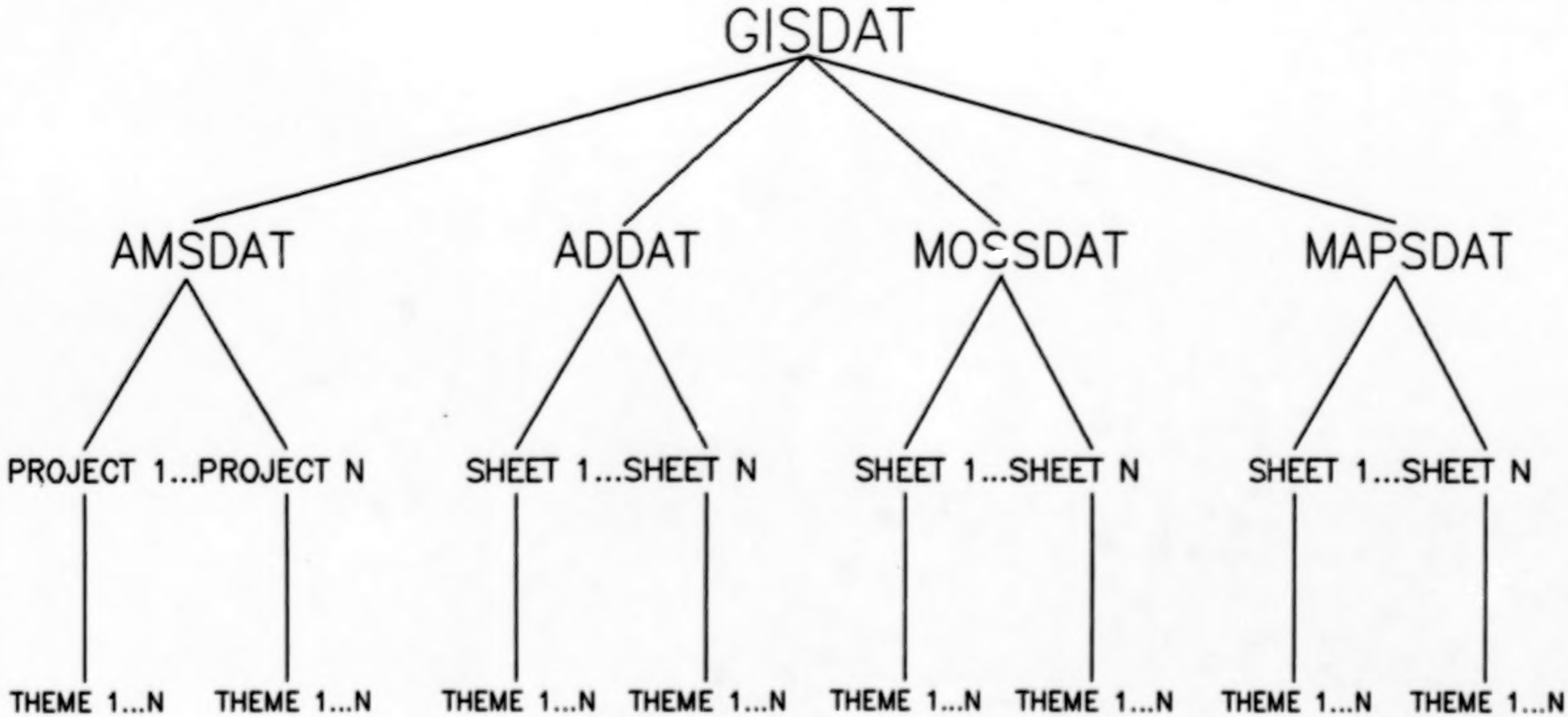

Figure 4

Flow of the ALBE GIS Data Processing

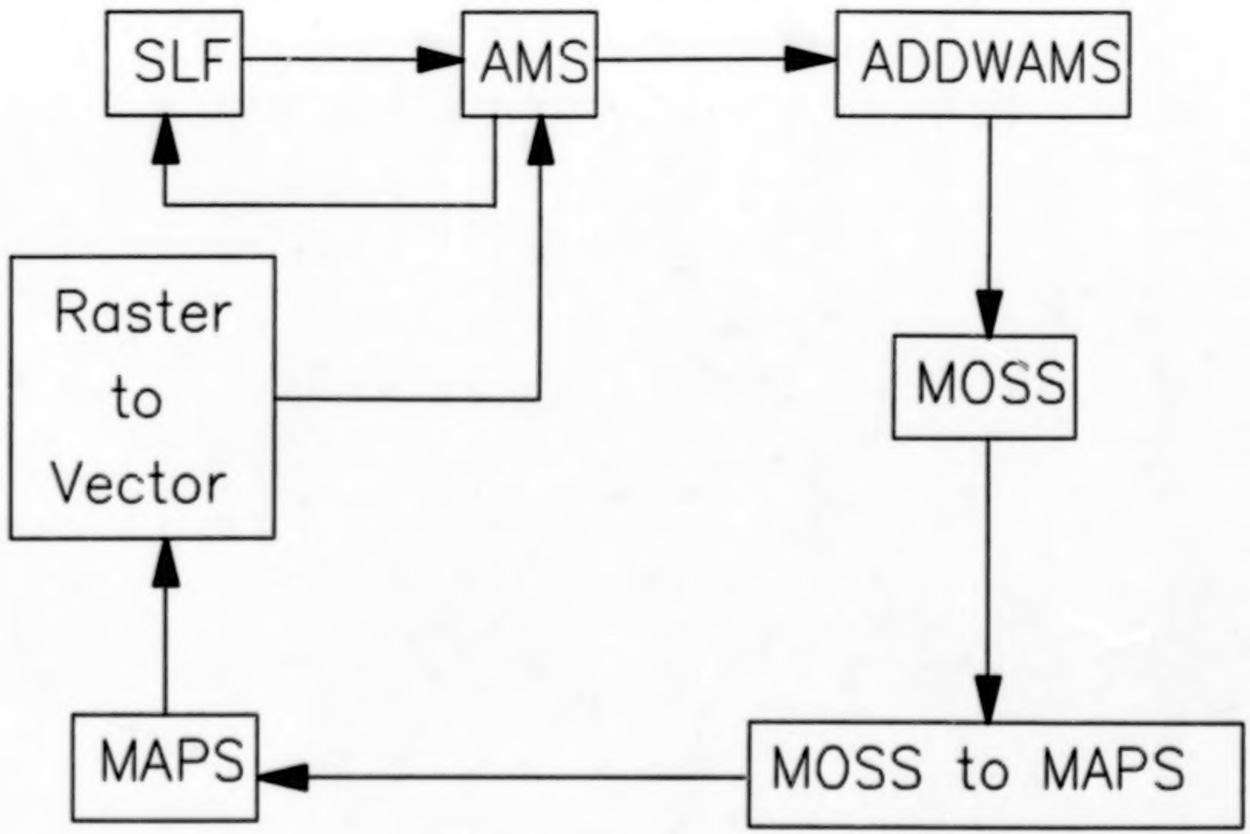

Figure 5

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directly transfered. The DMA digital data standard is in a state of transition. 2-D SLF data (TAPS FECAT coding), 3-D SLF data (DMAFF coding), and MINITOPO data (FACS coding) is or will be available. ALBE GIS will continue to use the in-house attribute coding scheme, with plans to develop conversion programs for 2-D SLF to 3-D SLF to MINITOPO formats as needed.

The existing method for complexing maps or overlaying themes in MOSS is lengthy and is not user friendly. The installation of the Arcnode Overlay Processing module in AMS will allow the user to select from a menu of complexing options. These options include forming unions, intersections, or differences of data sets. The majority of the Arcnode Overlay software is written in C, with the remainder in FORTRAN.

The user exports the data through ADDWAMS by selecting an option from an AMS menu. The ADDWAMS module allows the user to select a map projection, converts the data to ASCII and prepares it to be added to the MOSS database. The data is stored in polygon form, with common vectors duplicated.

4.3 Map Overlay Statistical System (MOSS)

MOSS is a command driven analysis and display system for map and other geo-based information and is designed to allow users to retrieve, analyze, and display maps and spatial data stored in the system. ADDWAMS data is added to the MOSS database by selecting the ADD option from the MOSSUTILITY menu. The data then exists in binary, MOSS format and is represented in vector form. Processing capabilities of MOSS commands can be broken into three groups:

MOSS - program control, and map data storage and description
MOSSANALYSIS - extraction and production of information from existing map data, usually resulting in a new map

MOSSUTILITY - general housekeeping and display of map files

MOSS data is stored in binary, MOSS format. Polygon information is preserved, with duplicate storage of shared segments.

4.4 Map Analysis and Processing Subsystem (MAPS)

Copies of the MOSS data files are generated in the MAPS database by executing the MOSSTOMAPS command. A header file, which is used to recognize the data files existing in the MAPS database is also

created at this time. The RASTERIZE command can then be used to rasterize these MOSS files. Once the data has been rasterized, it exists in binary MAPS format. Polygons and segments are not preserved in MAPS. The MAPS format represents a geographic area as a grid of pixel values, with each attribute assigned a unique number. MAPS contains processing capabilities in groups similar to those of MOSS: program control, data storage, data display, and data analysis.

MAPS data, as well as other forms of raster data, can be processed further by the Raster to Vector conversion module. The user will be able to display raster data in vector form via the conversion. Data from image processing sources can be vectorized with this software, and vector and raster data sets can be converted to the same form for merging. This enhancement will also be designed to close the loop on the GIS data processing. In this way, raster data from outside sources could be brought into the ALBE GIS system, assigned attributes, and processed for use in TDA production. Three types of raster to vector conversion will exist: creating polygons or areas (soils, slope), linear features (lines, roads), and contours (elevations, moisture gradient). ICARAS, a FORTRAN package created by the EROS data center, will be used for the creation of polygons. A FORTRAN package created by BATTELLE will be used for the creation of vector contours. DBA will design the software for creating the linear features, as well as integrating the aforementioned packages into the system. Any additional software such as utility programs or libraries will be written in C.

5. TACTICAL DECISION AIDS

The ALBE Tactical Decision Aids are software products which predict the effects of environment on both friendly and threat materiel, weapon systems, personnel and operations. The TDA's are not intended to render decisions, but rather to supplement the tactician's knowledge base and augment the decision making process by providing information useful in the formulation and execution of battlefield strategies. The inputs to generate these products consists of Digital Terrain Elevation Data (DTED), digitized (at Army labs) Tactical Terrain Analysis Data Base (TTADB) terrain feature data, historical climatological data, near-real-time meteorological data, and miscellaneous information such as vehicle and bridge parameter lists, data on military equipment, personnel, etc. The Defense Mapping Agency has agreed to produce DTD (digitized terrain feature data) as part of their Mark 90 program in response to a request by the Army for higher resolution data. The DTD data will serve as the terrain data base for the ATB and other Army advanced technology systems.

ALBE TDA's cover the effects of both the current and forecast state of the environment. They enable the tactical commander and his staff to evaluate weapon system effectiveness, determine the advantage of one system over another, and anticipate how operations will be degraded or improved during threat/U.S. engagements. The TDAs will enhance the ability to plan and execute operations in a dynamic tactical situation, and let commanders and their staff use weather and terrain as force multipliers in employing combat assets.

There are six ALBE Tactical Decision Aid categories. They are:

Army Aviation
Countermobility
Ground Mobility
Nuclear, Biological, Chemical (NBC)
Terrain and Atmospheric Utilities (TAU)
Weapon System Performance

Each TDA category contains a number of modules; and each module produces one or more TDA products. The products of some modules can serve as input for those of another category. TDA products generated through these processes will not merely reflect the effects of any single factor, such as terrain, weather or battle-induced conditions, but rather the combined synergistic effects of a number of factors.

5.1 Army Aviation

The Army Aviation TDAs will demonstrate the application of terrain and atmospheric models in analysis of aircraft performance as it contributes to the success or failure of an aviation mission. The TDA software generates both graphic plots and textual reports as output. The category consists of three modules;

Flight Weather
Aircraft Vectoring
Aircraft Performance

The Flight Weather module generates information on weather hazards to helicopter flight. Five interactive models allow the user to analyze different scenarios. Aircraft Vectoring allows the tactician to assess, predict and plan various aircraft operations. Ten interactive models allow the user to generate data that describes the current status of selected aircraft instrumentation and analyze the potential impact of environmental and terrain conditions. Aircraft Performance generates graphical displays and map overlays of density/altitude information for

flight planning purposes. The input, either current or forecast meteorological data, is used to determine the areas where aircraft performance may be marginal or hazardous.

5.2 Countermobility

The Countermobility TDA's will make predictions of obstacle deployment and effectiveness considering the environment, troop and equipment assets, constraints on equipment operation and time required. Obstacles addressed include: minefields, wire, craters, rubble, ditches, log obstacles, and flood zones. The products generated allow the evaluation of alternative plans and reduce the time required to implement an integrated obstacle system. The category consists of three modules;

Minefield Deployment Effectiveness
Obstacle Deployments
Obstacle Systems

Minefield Deployments predicts the effectiveness and uses data from environmental sensors located in the area of interest to make real time predictions. This software allows the tactician to generate map overlays illustrating deployment performance, effectiveness, sitings, and resource requirements. Site selection products are generated using mobility, gap crossing and Line of Sight predictions which are products of other TDAs. A supporting model that addresses the impact of snow cover or frozen soil on the effectiveness of a minefield will also be implemented.

Obstacle Deployment software allows the tactician to generate a product(s) which predicts the effectiveness, location and logistics of obstacles other than minefields. Obstacle System software allows the tactician to generate overlays which show location, estimated threat force breaching times, movement restriction, time delay effectiveness and logistics. Obstacle System predictions will be available for winter conditions; ice, snow and frozen surfaces. The capability provided will enable the commander to plan tactical countermobility operations efficiently.

5.3 Ground Mobility

The Ground Mobility TDA software generates a comprehensive description of the ability of vehicles and vehicle convoys to transport men and material over virtually any type of terrain, on

or off road, under nearly any weather conditions. Battlefield environmental conditions are described either on a projected or on a near real time bases. This will allow the tactician to use the products in either pre-battle planning or in battle decision making. The category consists of eight modules:

Off Road Speed
On Road Speed
Bridge Evaluation
Gap Crossing
Formation Movement
Route Cover and Concealment
Integrated Mobility
Road Usage

The Off Road Speed module is designed to predict the "GO/NOGO" and maximum speed performance of vehicles off the road considering the degrading effects of terrain and environmental conditions. Predictions can be adjusted to either agree with long term weather forecasts or reflect near real time weather. The tactician can generate map overlays including depiction of the ground vehicle "GO/NOGO" speeds, and speed performance both on an areal and a route selection basis, comparisons of off road speed capabilities of different vehicles, and reasons for vehicle off road speed reductions and NOGOs. On Road Speed module products consider vehicles operating on undamaged segments of a road and provides similar capabilities as those for Off-Road module products.

Bridge Evaluation identifies the location and characteristics of fixed bridge sites and indicates the suitability of a site for tactical bridge deployment. Gap Crossing evaluates vehicle geometry and traction performance capability relative to gap characteristics and predicts the ability to cross at selected sites. It includes a supporting model: Winter Bridging, used to locate tactical bridging sites in cold weather environments.

Formation Movement software is interactive and is designed to aid in the logistic problem of relocating manpower and resources. Route Cover and Concealment software predicts the capability of vehicles to travel on the battlefield with minimum exposure time. The resulting products can be used in combination with others to plan routes that minimize risk. Integrated Mobility is a combination of all the previously described modules. It can predict speed and/or travel time for vehicle movement either on road, off road, or across gaps; and it can generate route selection maps interactively. Road Usage software predicts the influence of road usage (vehicle speeds, traffic volume, movement

times) on road damage and repair. A supporting model; Resource Planning, incorporates Ground Mobility TDA applications into the Engineer Command and Control System (ECCS) for mission planning.

5.4 Nuclear, Biological, Chemical

The Nuclear, Biological, Chemical (NBC) software generates products which provide information on the location, extent and persistence of NBC hazards and smoke; the side effects of chemical protective clothing; and options for decontamination. The category consists of four modules:

NBC Hazard
Smoke Generation
Tube Delivered Smoke
Chemical Decontamination

NBC Hazard automates reporting operations and provides the capability to display two and three-dimensional nuclear fallout and chemical hazard areas on digital terrain map backgrounds. Smoke Generation automates the design of large area oil fog smoke screens to provide concealment and deception and to prevent operational use of various electro-optical systems. Tube Delivered Smoke uses munitions delivered by howitzers and mortars for the same purposes as Smoke Generation products. Chemical Decontamination provides the guidelines for NBC decontamination on the winter battlefield identifying, interactively, practical options for different types of equipment.

5.5 Terrain and Atmospheric Utilities

The Terrain and Atmospheric Utilities (TAU) software provides general supporting utilities which can generate stand alone products or feed data into other TDA software. The tactician can use this software to generate either graphic or textual reports of terrain and weather effects on varying military operations. The category consists of seven modules:

Intervisibility
Sensor Communication and Data Handling
Weather Effects Messages
Surface and Upper Air Data
Military Hydrology (MILHY)
Target Area Winds
3D Perspective View

Intervisibility software is interactive and allows the tactician to generate eight distinct terrain based products which predict the impact of line of sight (linear and radial) on mobile and aerial military operations. The Sensor Communication and Data Handling software is really ATB system level software which allows for the input of environmental data from any meteorological sensor and make it useful for the TDAs. The Weather Effects software allows the tactician to either scan the environmental data base for parameters in excess of pre-determined critical values and warn of the potential weather impact or allows the tactician to simulate a scenario with a given set of climate/terrain values in order to determine critical considerations and effects to a number of operations.

Surface and Upper Air Data software integrates diverse environmental measurements into a coherent depiction of the current status of the weather aloft and at the surface. This software also allows the tactician to generate contour map overlays of specified met parameters in the area of interest. These products chiefly serve the interest of the Staff Weather Officer (SWO) personnel.

Military Hydrology software allows the tactician to predict forecast of water stage and flow characteristics for selected times and cross sections within an area based on the physical watershed characteristics and the precipitation as measured by ground sensors. Target Area Winds software provides an accurate estimate of terrain influenced surface and upper level winds in target areas, ahead of the Forward Line of Own Troops (FLOT) and in other data-silent areas. Knowledge of terrain influenced wind fields will produce more accurate chemical hazard and smoke screen predictions, and will aid in the proper placement of chemical alarm sensors and billeting of troops. The 3D Perspective View software allows the tactician to generate a shaded relief terrain perspective view product which can be used as a stand alone product to provide the commander with a realistic window to view the battlefield environment or as a background map onto which could be draped a time/event sequenced chemical or smoke generation product. The latter example would depict the influence of the terrain and wind field as the cloud plume disperses throughout the area of interest.

5.6 Weapon System Performance

The Weapon System Performance software considers the impact of environmental effects on the effectiveness of electro-optical and seismic/acoustic sensors and systems. The tactician can use the software to generate information for friendly and threat conditions, currently fielded and developmental imagers, lasers,

and guidance devices such as used on the TOW; self contained munitions such as SADARM; advanced munitions such as FOG-M and AAWS-M; and aided target recognition (ATR) devices. The category consists of four modules:

- Electro-Optical Systems
- Top Attack Self Contained Munition (SCM) Systems
- Seismic/Acoustic Sensor Systems
- Advanced Munitions

The output for Electro-Optical Systems will consist of tables depicting the effective ranges of devices used for target acquisition and map overlays displaying line of sight limitations on the terrain. Top Attack SCM system software will predict the performance of different target types, sensor logic and sensor scan characteristics and it will determine optimum terrain deployment sites for SCM/target engagements. Seismic/Acoustic Sensor Systems will provide techniques to detect, locate, and classify threat vehicles. Advanced Munitions will predict the performance of automatic target recognition devices in current of forecast environmental conditions.

THE DEVELOPMENT OF SMALL COMPUTER GEOGRAPHIC ANALYSIS SYSTEMS FOR MILITARY APPLICATIONS

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ABSTRACT

Georgia Tech has a long history of developing complex geographic data processing capabilities on small computers. Four such systems, SATELLITE, TAWS, Microfix, and Penaids were developed to aid in the planning of various military operations. Each system emphasized the underlying spatial structure of the application and the inherent difficulties of processing large amounts of geographic data on small computers. The first software system, SATELLITE, began in 1971 for the processing of Landsat satellite imagery. SATELLITE was one of the first image processing implementations on mini computers. TAWS, the Terrain Analysis Workstation, was developed with

the U.S. Army Engineering Topographic Laboratory (ETL). TAWS, a pioneering effort in using the DMA Digital Terrain Elevation Data (DTED), provided capabilities for generating perspective views of terrain, visibility plots, and mobility information. Microfix was developed in 1980 for U.S. Army FORSCOM. The Microfix system was the first fielded system using video disk map technology providing zoom and scroll over map imagery coupled with a point database of intelligence data such as order of battle, airfields, roadways, and bridges. The concept of using a relational database for geographic data was carried a step further in the Penaids mission planning system developed for the U.S. Air Force TAC/DRIB. Penaids supports a full relational database of point, vector, and polygon data allowing queries based on geographic location and other attributes. Other data sets used within Penaids include DMA DTED and CIA WDBII. Capabilities were provided within Penaids for determining the limits of visibility for hostile defense radars. Additionally a geographically distributed probability surface is constructed from threat effectiveness models and, consequently, used for aircraft path optimization.

1 INTRODUCTION

Geographic information systems are now being used by many different types of organizations with widely varying functional requirements. However, virtually all GIS systems share functional similarities due to their common needs for positional accuracy and large geographic databases. Likewise, most developers of GIS system encounter many of the same problems during the definition of the system requirements, development and testing of the software, and the fielding and maintenance of the system.

In order to put GIS capabilities in the hands of the largest number of users, an organization would prefer the least expensive computer system realistically capable of running the GIS application software. The GIS developer, then, is faced with the fundamental tradeoff between decreasing response times and increasing system cost. Fortunately a number of relatively low cost hardware and software options such as disk i/o cache, special pur-

pose coprocessors, and optimized math libraries can dramatically improve system performance. Often, however, these low-cost options increase development time and can reduce software portability.

The goals of an operational military GIS often produce contradictory requirements. For example, the need for worldwide deployment and portability necessitates a small inexpensive computer yet the global databases require large and expensive mass storage devices. Obviously, some hardware technologies fare better than others in harsh rugged environments, a limitation in selecting the best computer for the job. Finally, special attention to ease of use and system maintenance must be paid since the military personnel may be inadequately trained or under extreme time constraints.

2 A PROJECT HISTORY

The Georgia Tech Research Institute (GTRI) has a fifteen year history in the development of computer systems for geographic information processing and analysis. The experience at GTRI, illustrated in four such systems, highlights not only the problems inherent to working with geographic data on small computers but also how GIS development has changed over the last decade and a half due to the dramatic advances in hardware, software and GIS understanding.

2.1 Satellite, 1973-present

The history of Georgia Tech's involvement with small computer military GIS systems first began with the development of a civilian image processing system for Landsat data named, appropriately enough, Satellite.

The Landsat 5 satellite maps the entire earth approximately every two weeks. The imagery it generates has a resolution of 30 meters with seven channels of data including three visible, three infrared or near-infrared, and one lower resolution thermal channel. Such data has inherent problems due to cloud cover, geographic rectification, and the amount of computer

processing and data storage required because of the volume of the data.

Capabilities provided within Satellite included the tape utilities necessary to load the voluminous Landsat data. Likewise, the abilities to rectify the raw Landsat data to produce a geographically correct image were also provided. The rectification functions required that the problems of converting between two different geographic coordinate systems be solved, in this case, UTM and latitude and longitude. Images could be saved to file, tape, or displayed on a graphic display device.

Satellite was implemented on a Data General S/250 computer running the RDOS 6.42 operating system. The system also included a RAMTEK image display system.

2.2 Terrain Analysis: FEED and TAWS 1982-present

Georgia Tech became involved with computer processing of digital terrain data first, in 1982, with the FEED system, and then, in 1984, with the TAWS system.

The FEED software and hardware system was developed by U.S. Army Engineering Topographic Laboratory (USAETL) to demonstrate that digital analysis of terrain information could occur in field situations. The FEED system was composed of a ruggedized computer system installed in a van. Software developed at USAETL was converted to the ruggedized system and the van started a tour of major Army bases in the continental U.S. Georgia Tech was chosen to support and improve on the terrain analysis software in the FEED system. This support involved participating in field exercises and assisting in demonstrations as well as ongoing software development. The initial FEED software ran on a system with a 32k program space limit, thereby necessitating an extensive use of swaps and overlays. Subsequent Georgia Tech versions of the FEED software have been implemented on Data General Eclipses and Digital Equipment Corporation's PDP 11 and VAX. An example of a terrain mask produced by FEED is shown in Figure 1.

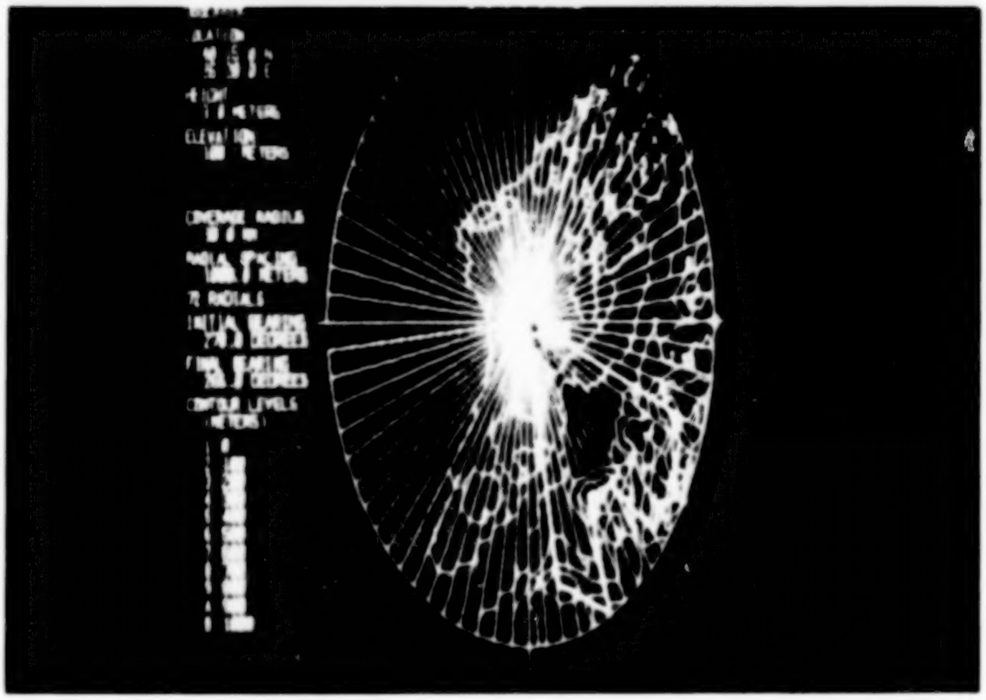

Figure 1: An Example of a Radar Terrain Mask from FEED

In 1984 Georgia Tech was selected to develop terrain analysis software for the TAWS system being developed by USAETL. The TAWS configuration is based upon a Hewlett Packard 9000 thirty-two bit mini/microcomputer and a Unix-like operating system (HPUX). Line of sight algorithms had been developed by USAETL for the Field Exploitation of Elevation Data (FEED) project and the Digital Terrain Analysis System (DTAS). This software was modified extensively to take advantage of the large address space of the HP9000 and it was implemented with a device independent graphics package.

Perspective three dimensional views, terrain masking, line of sight profiles, elevation and slope contouring are available on the TAWS system. Figures 2 through 5 present examples of displays available on the TAWS system. An interface with optical equipment and a polygon database manager allow for updates of digital terrain and feature data bases.

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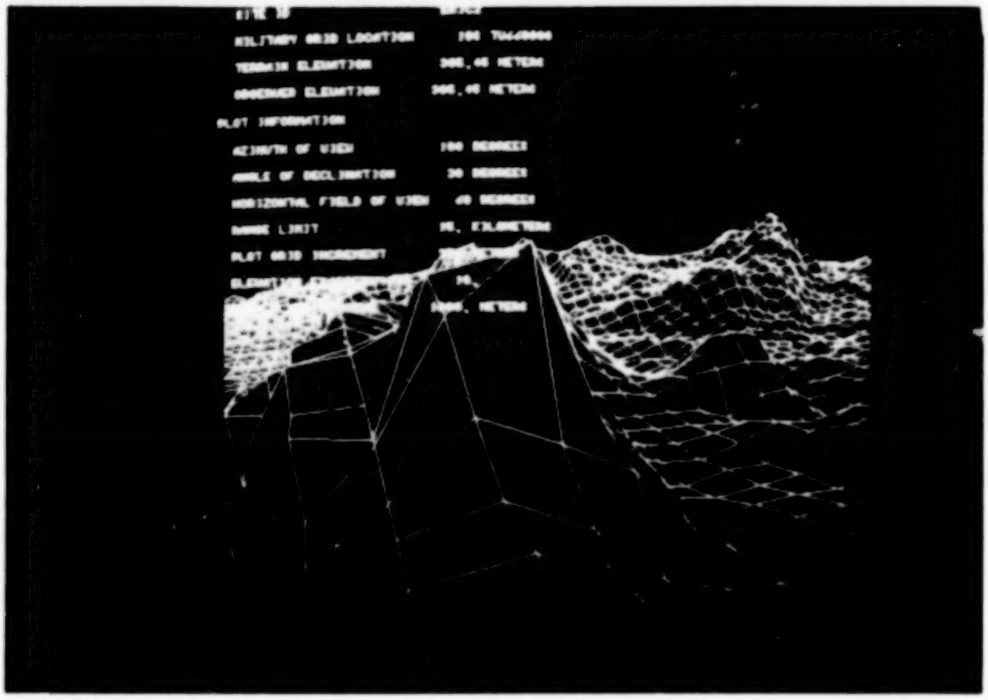

Figure 2: An Example of Wireframe Terrain Perspective from TAWS

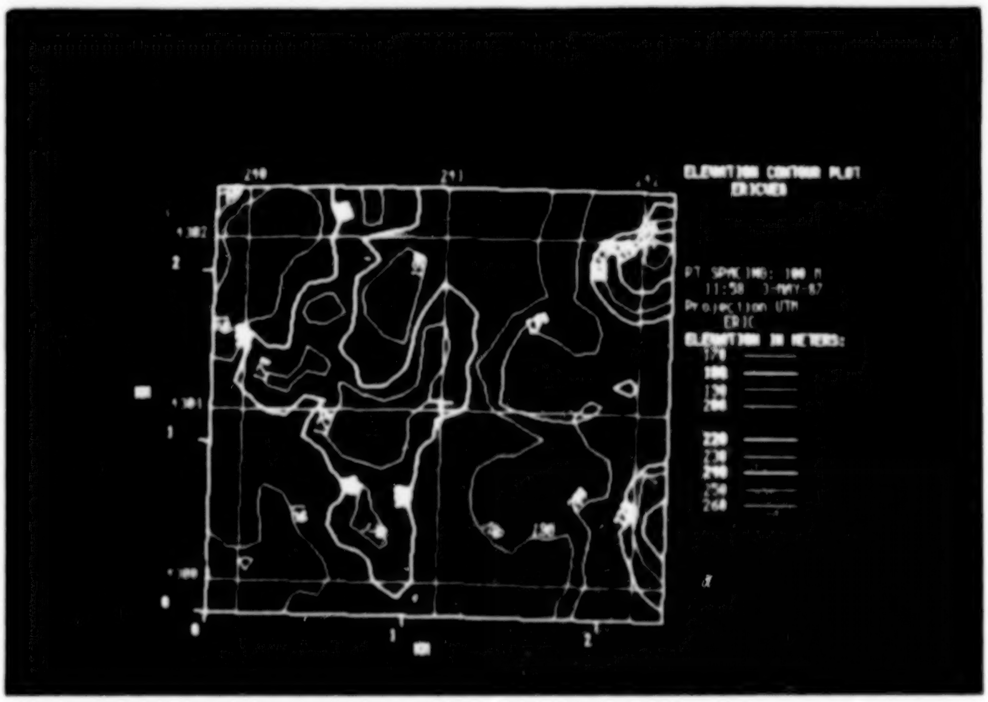

Figure 3: An Example of Elevation Contour Display from TAWS

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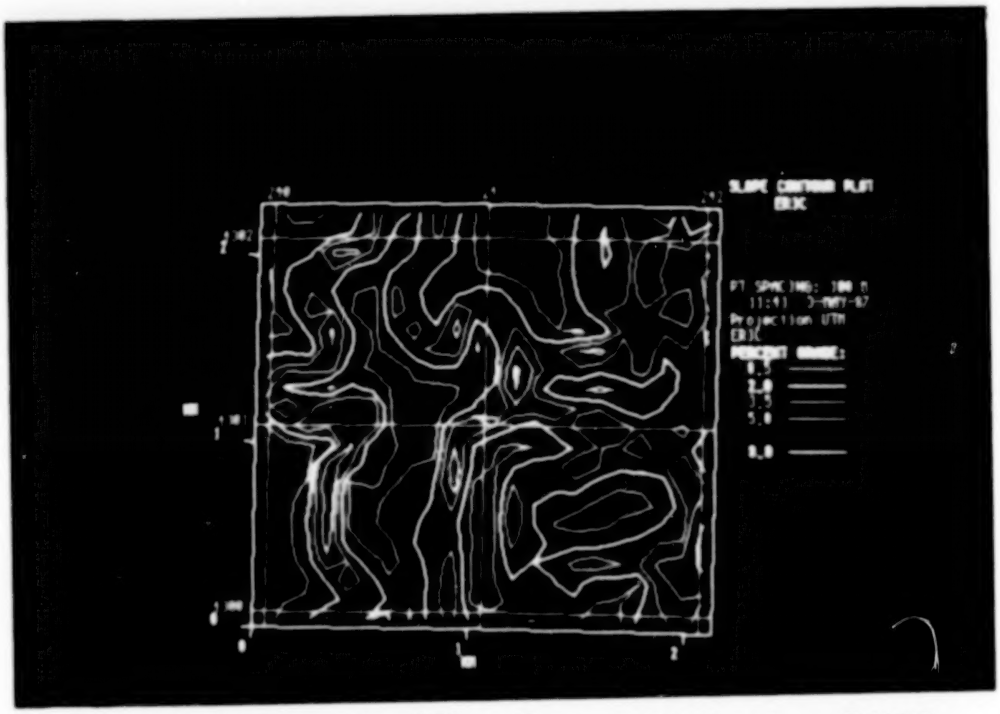

Figure 4: An Example of Slope Contour Display from TAWS

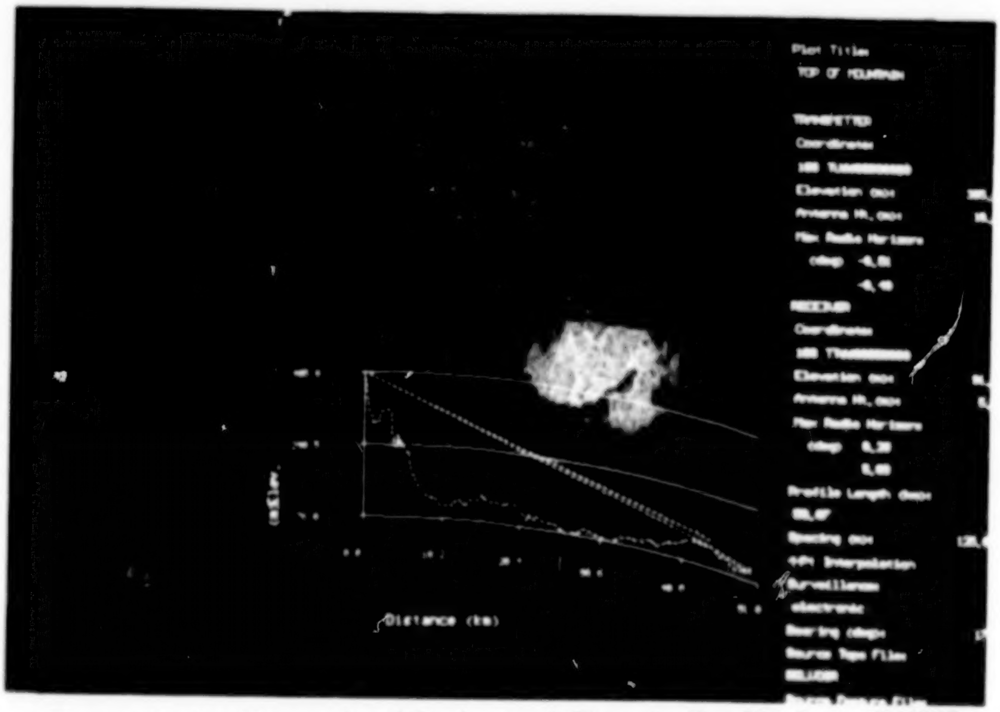

Figure 5: An Example of Radar and Terrain Profile from TAWS

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2.3 MICROFIX 1981-present

Georgia Tech became involved with the U.S. Army Forces Command (FORSCOM) during the early 1980's. FORSCOM had distributed Apple computers to units in the field and had a need for application software for various operational uses. GTRI performed a needs analysis and determined the most common requirement was to automate the "shoebox of cards". Upon further examination it was discovered each card shared the common attribute, geographic position.

MICROFIX quickly evolved into a tool for "situation assessment". The user was able to see the positional relationship between different data items and their surrounding terrain. The ability to display the surrounding terrain and map features was provided by the use of video disk maps. The storage and processing limitations of the Apple computer made it impossible to use any digital map feature database like WDBII. The maps were filmed at three zoom levels and with 60 percent overlap between each frame. Each frame was stored on a video disk capable of storing up to 54,000 frames. Since no processing of the map background was required, the solution was ideal. MICROFIX demonstrated that all the features and capabilities promised with video disk technology can function in the field under harsh conditions. A number of other organizations have explored applications with video disk mapping including Decisions and Design Inc., Chrysler, Perceptronics, and others.

The system consisted of a Apple II+ microcomputer with additional expansion equipment which included a 128K RAM card, Z80 microprocessor card, video interface card, and graphics video card among others. The system contained a monochrome monitor, a color monitor, keyboard assembly, hard disk, graphics tablet, and videodisc player. The development software included dBaseII and Pascal MT+.

2.4 Penaids 1984-Present

The Penetration Aids System (Penaids) was developed over a three year period at Georgia Tech for use by the Tactical Air Forces worldwide beginning in 1988.

Penaids is a planning aid for low altitude air routes taking advantage of the terrain masking effects on hostile air defense radars. The primary geographic data bases used are the DMA Digital Terrain Elevation Data (DTED) and the WDBII map feature data. Figure 6. shows an example of a gray scale of the DTED data over the northern European area. The software associated with radar data processing include capabilities for digitizer input of intelligence data on current enemy radar locations, terrain masking based on line of sight using DMA DTED, and graphics display of point, feature, and polygon data superimposed over WDBII map feature data. Figures 7 and 8 illustrate the effect of terrain masking at low altitudes. Figure 7 shows the circles representing the limits of the nominal radar range. Figure 8 is a plot of the terrain masks for the same radar locations. Political boundary information extracted from the WDBII data set is also displayed.

The mission planning capabilities include generating geographic probability surfaces and gridded representations of the polygon database. These additional data sets are then used for automatic generation of optimal paths between any two points, or for analyzing the effects of the polygon data upon the path. Additionally, the optimal path capability includes turn constraints, fuel limitations, and altitude optimization.

The computer hardware used during the course of the Penaids system development included a Cromemco CS250 68020 based Unix system with a Conrac graphics monitor, VT220 terminals, a GTCO digitizer, and a dot-matrix printer. Software included Unisys Unix operating system and utilities, the Unify relational data base management system, and the Pascal computer language.

Figure 6: European Area Terrain Data Set from Penaids

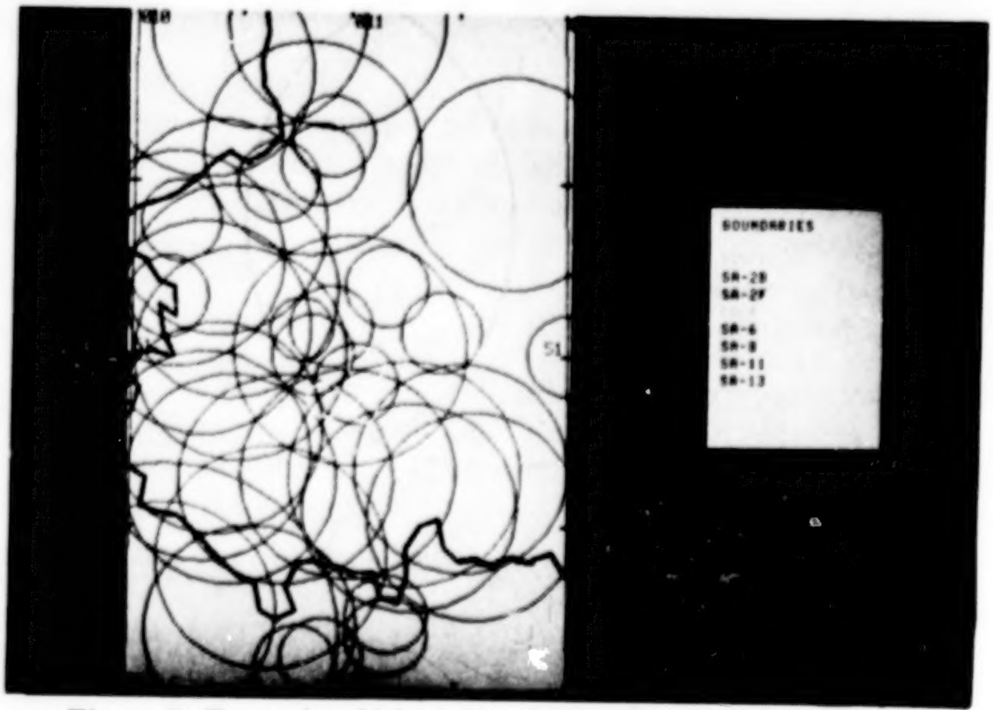

Figure 7: Example of Maximum Radar Coverage from Penaids

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Figure 8: Example of Terrain Masked Radar Coverage from Penaids

3 OBSERVATIONS

Viewing the four systems discussed in this paper over time reveals some significant points for anyone contemplating GIS development. Certainly, the definition of the system requirements is central to defining what GIS capabilities are needed. The capabilities coupled with the data problems will determine hardware and software specification. In turn, smart selection of the hardware and software components can reduce the software development effort.

3.1 Defining System Requirements

Satellite and FEED/TAWS were both firs: attempts using new data sets and as such focused on the application softv/are to effectively use these new image and terrain data sets. However, Mic.ofix and Penaids both tracked point data that moved over time; both sy:tems provided situational as-

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sessment based on the best information at the time. Consequently, both Microfix and Penaids made use of commercial data base management systems to provide attributes for point data.

Penaids was the first system, of the four discussed, that was actually designed with the awareness that the system was inherently a GIS, though with specialized applications and data sets. Consequently, the Penaids system design includes a very flexible set of software tools for handling geographic data and analysis. It is important to note, however that the military organization that sponsored Penaids was urgently concerned with solving its operational problem and not fully aware of the benefits of GIS technology. Understandably, the responsibility for educating operational military units about their underlying GIS problem falls on us, the GIS developers.

3.2 The Data Issue

Digital data, though voluminous, is usually available in some machine readable form. The Defense Mapping Agency provides both a digital feature and terrain database for use by military agencies. Additionally, the CIA World Data Bank II data set offers worldwide vector data denoting political boundaries, rivers, lakes, coastlines, etc. Typical problems include the ability to read the particular data format, geographic registration and rectification, processing by data category or type, and the determination of an adequate sampling interval to maintain the necessary accuracy yet reduce on-line storage.

Analog data, on the other hand, poses significant data capture problems. The two most widely used techniques for obtaining data from analog maps and imagery are the vector oriented digitizer pad, or mouse, and the image scanner, or video digitizer. Alternatively, video imagery might be desirable for an "information only" background display which would simplify the capture process but still require the need for geographic control.

3.3 Software Development

Both the Microfix and Penaids projects made extensive use of commercial database management packages, which provided very powerful and reliable data access, especially for point and feature data. The same notion of selecting the best available software to reduce the development effort carries into the selection of the programming language. Both Microfix and Penaids were written predominately in Pascal, a strongly typed language, which encouraged modular development and reduced programming errors.

In testing software for geographic processing experience has shown it important to select areas with extreme and unusual characteristics such as rough coastal terrains straddling mathematical boundaries like the date line or the equator. For design, development and testing use databases of realistic size.

3.4 Radar Terrain Masking

Radar systems play an important role in military operations. The differences in how radar terrain masking was handled between FEED, TAWS, and Penaids sheds some light on how approaches to GIS development have changed.

With FEED the radar terrain mask was first generated with the then new DMA DTED data. In order to reduce the requirements for data storage, a polynomial representation of the elevation was used. Disk accesses were slow and time requirements to generate a mask using radials going out at one degree increments were upwards of an hour per mask. TAWS brought with it a block oriented paging scheme using the actual elevation points with a resulting improvement in response times. Penaids, however, started with a study of the effects of DTED sampling rate and azimuth spacing on response times and mask quality. This subjective study recommended the use of a subsampled DTED coupled with five degree azimuth increments.

Finally, the locations for the radar site were stored in a relational data base in Penaids. The attributes associated with the type of radar, its height,

range and other characteristics were also part of the same relational data base. Also, pointers to a polygon file management system were maintained within the radar attributes for storing terrain masks at different altitudes. The computation technique was also different in that a reserved area in main memory, one megabyte in size, was maintained for loading in the required terrain needed for an individual mask. Since masks tended to be processed within a geographic window, page changes were reduced and all computations were memory accesses instead of disk accesses, thus improving run time. Terrain masks on the Penaids system could be generated at over four masks per minute depending on radar range.

3.5 User Interface

The quality of the user interface improved dramatically from the earlier FORTRAN based Satellite and FEED/TAWS systems. The Satellite system, though menu driven, prompted the user for necessary runtime information which scrolled off the screen as more prompts were displayed. FEED and TAWS functioned basically the same with the user putting in extensive information to produce a terrain mask. In contrast, the Penaids system provides full screen editing of the data entry and type dependent error checking for each field of data. Additionally, when entering a new radar location the Penaids user need only specify the radar type and the corresponding attribute information is automatically updated.

One perspective on the evolution of user interface is that initially the focus of development was the application only. With increasing computer power, the emphasis began to include ease of use.

4 FUTURE TRENDS

Given the rapid improvement of computer hardware and software, we can anticipate increasing expectations from GIS users. User requirements will, in the near future, include analysis based on multiple data sources of differ-

ent types. Much future work will include developing new and better ways of getting the data into GIS systems. Likewise, with the availability of more accurate and timely data, user requirements will grow to include temporal analysis such as urban growth and change detection. Consequently, graphics presentation techniques like three dimensional perspective of analysis surfaces and animation will become commonplace.

To the military organization which must operate over a very large geographic area, the future improvements in computer hardware technology will mean greater flexibility in how the large global data sets are stored and processed. As magnetic and optical storage technologies increase in density and data transfer rates, the "small" computer system will begin to have on-line storage in excess of 1 Gigabytes in the near future. The larger on-line storage will allow very rapid access to data that previously had to be stored on magnetic tape and loaded before processing (often requiring hours to do so). Larger random access memories will mean larger blocks of data can processed before accessing disk, thus dramatically improving the performance of operation requiring large amounts of memory.

Digital elevation models will become common on GIS systems due to its many uses. Likewise, the use of presently rare and/or real-time data sources, like Global Positioning Satellite data, will increase.

One important trend is that of increasingly powerful software development tools. The Satellite and TAWS projects were done using the FORTRAN programming language and the FLEX preprocessor that provided more structured control than the early FORTRAN. Both Microfix and Penaids were done in Pascal, a strongly typed language, and both used commercial database packages for the database. The future will bring us more extensive languages and development tools, and they should be utilized to reduce software cost. The trend toward increasing use of the Ada programming language, with its software engineering features and environment, is a welcome one.

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THE ENVIRONMENTAL GENERALIST AND DISCIPLINE EXPERTS IN LDC ECONOMIC DEVELOPMENT PLANNING

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ABSTRACT

Economic development in most lesser developed countries (LDC), especially in tropical zones, involves agriculture, forestry, fisheries, and to a lesser extent in today's global economy, mining. Lessons from past and recent development projects show that lack of attention to environmental concerns and planning (in detail and integrated) have resulted in short-term yields with little thought to sustainable utilization of an environment. Neither have there often been serious attempts at reversing the environmental degradation that resulted from the drive to exchange natural resources for the hard currency from industrialized countries that is necessary, in theory, for the sustenance and growth of LDC economies.

Environmental planning is an integrative procedure in which discipline experts work on limited study goals within the focus of a project that has the highest potential for productivity or that meets the greatest needs of a region or a nation. It is the environmental generalist, however, who assembles the results from the experts and evaluates their combined impact on a development project environment. This generalist should be a "hard scientist" who uses observations and measurements to make interpretations based on the multiple-working hypothesis approach, and logic in setting forth conceptual models that have the highest probability for project success under the limitations given by the experts. Models that are the basis for investment decisions should include natural and man-caused catastrophic events as a necessary part of benefit-cost analysis.

The conceptual models are formulated in terms of the sector or sectors for investment (e.g., agriculture, forestry, fisheries, and mining), the infrastructure to support a total development package, and environmental

data on geology, soils, vegetation, landform, hydrogeology, and other observable and measureable characteristics that lend themselves to graphic representations from aerial photos and satellite imagery after ground-truth checking. Together, the various factors from the environmental analysis yield a land capability map that allows ratings of terrain and environment for specific (linked or unit) development projects within the framework of integrated environmental expertise focused on regional and/or national aims and realities.

1. INTRODUCTION

The economic development planning in many LDCs is based on the exploration for and evaluation of natural resources. Sectoral emphasis centers on agriculture, forestry, fisheries, and less so at present demands, on mining. The implementation of any project in these or other development fields involving the exploitation of natural resources requires the appropriate infrastructure in one or more additional sectors (e.g., energy, transportation, industry). Each sector and coupled infrastructure program will impact on the environment. Multisector development projects will have greater potential for environmental impact.

Ideally, the planning stage for economic development based on natural resource exploitation will be predicated on three principal objectives espoused by multilateral lending institutions*. The primary objective is that the project results in sustainable economic growth**; secondly, the project should alleviate poverty by providing employment opportunities in the development, infrastructure, service, and other support sectors; thirdly, and necessary to achieve the first two objectives, the project must proceed under environmentally sound planning and management norms that preserve the physical, chemical and biological integrity of local and regional ecological systems as well as socio-cultural values.

*These include the Interamerican Development Bank, The Asian Development Bank, The African Development Bank, and the major lender, the World Bank, in addition to commercial lenders.

**Mineral resources are non-renewable, thus non-sustainable.

In the study of the evolution and history of the Earth, the geologist makes observations and measurements and works with the tenet that the present is the key to the past...that is, the dynamic processes that are operative on the earth today are the same ones that have been active during the 4.5 billion years of its history, but with the qualification that these processes have functioned at different rates. We can apply a modification of this concept in dealing with environmental projects: the past and the present are the keys to the future. We learn from past errors and from existing problem projects dealing with the sustainable development of an environment and make sure to eliminate them in the planning for a single project or linked projects.

It may not be possible to design the ideal project plan for one or a combination of reasons. For example, a plan will not proceed if necessary data are unavailable or insufficient. Nonetheless, it could proceed on the basis of incorrect or incomplete data submitted knowingly to an unsuspecting planning team. This puts decision making at risk. Complete and reliable observations and measurements and their interpretations should be done then by outside and inhouse discipline experts who will also make obvious connections between their specialties and others. This stage of selective technical linking between environmental parameters is essential to development planning.

2. PROJECT PLANNING

As an example of what must go into development planning with environmental requisites, let us examine a hypothetical project in the tropical zone. If there is poor environmental planning for a project in agriculture or forestry, for example, the natural resource base for the commodity (or commodities) being considered for sustainable development may be depleted to the point where it is a non-entity in the economic panorama. In addition, a cascade of environmental intrusions because of bad planning may disrupt or destroy other natural resources projects.

At present there is a strong world demand for hardwood timber and its value is soaring. Much demand in Asia is from Japan, a major consumer of tropical hardwoods for its furniture and construction industries, and from South Korea and Taiwan. This reflects the countries' strong economies. Timbering on Borneo is going on at an alarming rate to meet the demand and maximize income with little apparent heed to the intense environmental degradation that can be caused by unsound timbering practices1. This is not new. Tropical deforestation as a result of such practices is large scale in Southeast Asia, Africa and the Amazon Basin, and is continuing at a rate of 10 million hectares annually (over 97,000 km2)2 . In the Phillipines, for example, forested areas extended over 16 million hectares before large scale commercial timbering began. One-third of this area has suffered deforestation because of poor environmental practices, one-third with tropical hardwood remains to be worked in a manner that must be predicated on sustainable yield of the forests with a minimum of environmental intrusion, and one-third contains areas set aside as preserves to retain the genetic potential of the ecosystem. If the timbering were to proceed uncontrolled, as in the past, there would be more deforestation and intensified secondary problems such as the soil erosion that has ruined much of the productive land in Haiti and Nepal (removes nutrients and reduces yields) and threatens other large areas.

An assessment team going on mission to evaluate an economic development project for a government or an institutional lender
in terms of environmental protection and management will include experts for the development and adjunct fields. For example, a team of experts assembled to evaluate a forestry project in mountainous (high relief) areas in southeast Asia (e.g., in Borneo or the Phillipines), will have to cover several fields. An environmentalist will be one of the team leaders and will be concerned about the quality of the human environment. He/she may be a specialist in human ecology, and will be an advocate of the preservation or improvement of the natural environment and of the need to control pollution and other intrusions. The environmentalist need not be a "hard" scientist although his/her input to a project evaluation is absolutely essential.

As noted above, the past and present are the keys to the future in environmental planning. Thus, a review of problems caused by environmentally uncontrolled forestry exploitation in Borneo, in the Phillipines, and in similar topographic and climatological areas, will determine the disciplines that have to be covered by the planning mission.

3. SOME OF THE COMMON PROBLEMS

We can expect that the tall trees that are downed in the canopied forests at an acceptable rate of 25 per hectare may actually be causing a fall of up to 75% of the trees in an area because of the interlocking crowns, vines and webbing of the tropical forests. When the tree stripping is done and the logs are dragged to a riverbank down steep slopes over soil roads cleared of the vegetation cover, channelways for erosion are opened. Sediment follows these channelways silting in streams and rivers where discharge takes place. The siltation can ruin fishing grounds and if it degrades spawning areas on land, in transitional areas such as mangrove swamps, or in marine waters, fishery development may not be possible. The siltation can also disturb normal water use by indigenous groups in an area.

Because the tropical forest has poor soil systems but sustains a full growth by feeding on itself, any devegetation interrupts the natural cycle and diminishes nutrient in the soil and hence its productivity. Farmers will move into a former forested area, clear it out as much as necessary to allow it to be planted and then use a slash and burn agriculture technique. Since there is no replenishment of nutrient to the soil, it loses its fertility and becomes non-productive after a few years and the farmers move on to another area. Devegetation is exacerbated by the slash and burn agriculture and also results in increased surface water runoff and enhanced soil erosion and sedimentation. Siltation in the streams and rivers fills in the channels and decreases the volume of water that can move through them. Thus, a normal non-flood pre-siltation flow becomes a flood flow and what may have been a minimal flooding from a river channel becomes a major flooding event in both agricultural and urban areas. Associated siltation can clog irrigation channels and affect existing reservoir

and hydroelectric installations. When the environments suffer the intrusions cited above and others, whether in the forested watersheds being worked, or lowland and perhaps coastal areas, ecological habitats are being destroyed and biological diversity is lost.

4. EXPERTS

In the above scenario, several areas of expertise must be represented on an evalution team that will visit a potential development area. In the preparation for the mission, available maps of the area and remote sensing data from "normal" satellite imagery (80 meter resolution) or the very much more costly high resolution (to 30 meters) SPOT satellite imagery and other GIS systems must be studied and interpreted in consultation with the experts. The required disciplines include:

a. remote sensing - interpret maps, air photos, and satellite imagery
b. geography-geomorphology - land systems mapping from aerial photos (based on topography, soils, and vegetation) in terrain analysis for a specific project or group of projects
c. forestry - present latest technology for exploiting forests at an acceptable rate and transporting logs without disturbing forest cover thus reducing erosion and its consequences
d. uplands and lowlands farming - propose agricultural practices that will give a sustainable development and reduce erosion and its consequences
d. ecology - assess the existing ecosystems, requirements for their preservation and the maintainance of biological diversity
e. fisheries - establish tolerance to different degrees of environmental intrusion and requirements for their fisheries preservation
f. geology - geological science and its subdisciplines (e.g., hydrogeology, geomorphology) provide a broad base of environmental planning data. These span from evaluations of the very foundation rocks for man's structures, to the knowledge of the genesis of natural hazards (earthquakes, volcanic activity, landsliding, and flooding) and techniques of dealing with their prediction and in some cases prevention. In addition, erosion, sedimentation, surface drainage systems and

subsurface aquifers, and the mobility and dispersion of natural and anthropogenic geochemical contaminants are all geoscience research fields.

Geology is a cornerstone in environmental studies. The geologist's curriculum in most faculties includes chemistry, physics, biology, mathematics, statistics, and computer applications to problem resolution, thus qualifying him/her in a true sense as an environmental generalist. On the other hand, chemists, physicists, mathematicians and biologists most often do not have geology in their respective curricula and although there may be some cross coursework between these fields, it may also be limited or simply not done. We then have experts in their fields who may be missing a key element for overall environmental planning.

g. environmental sciences - an environmentalist "hard" scientist will integrate the data generated by other members of the assessment team and present a base model from which conceptual models representing different development scenarios are prepared; these can be presented graphically as 3-D models with land capability ratings in a way that can be easily assimilated and understood by the non - scientists who will ultimately decide on whether a development project should be approved and funded
h. benefit-cost analysis - natural hazards (e.g., flooding, earthquakes) and failures of man-made installations (e.g., dams, nuclear power plants) have probabilities of occurrence; economic losses associated with events have been determined; from an analysis of the frequency of an event (e.g., in real time or in terms of dam-years) and the economic loss caused by it, a probability function can be generated and entered into the benefit-cost study of a development project
i. socio-cultural impact of the proposed project must be established and solutions to human problems such as physical dislocation must be found that are accepted by the populations involved
j. economics - will determine if a project is feasible given the objectives of sustainable growth, alleviation of poverty, and environmental protection, and the potential for high productivity or to fill a need or requirement of a nation or region
k. if there are problems in the proposed project as it is evaluated, the assessment team led by the environmentalist must present alternatives.

Even when sound "hard" scientific observations and measurements, and social and economic considerations provide sufficient input to a project so that there is a balance between environmental protection and sustainable economic development, the project, in practice may not achieve the balance. Implementation of a project that will preserve the environment for long-term output in lieu of short-term yield may be obstructed because of several reasons. These include political considerations, lack of human resources to monitor and report upon real or potential environmental intrusions, and a perceived limitation of economic resources to realize environmental protection. With respect to this latter item, multilateral lending institutions' studies suggest that an investment of as little as 3 per cent of the total cost of many projects can result in the desired balance between environmental protection within the framework of sustainable growth3.

4. THE FUTURE

Although national development planning for many LDCs a decade or two ago was only nominally concerned with environmental conservation in the drive for economic progress, and importance of environmental degradation was minimized, today it is a high priority item.

It is clear that economic shortfalls can result from poorly planned projects which may also render an environment developmentally non-productive without costly and time intensive reclamation. This realization came from the grave problems that now affect many developed nations individually from past disregard for the protection of the environment, or regionally because of a physical linkage between countries such as common drainage basins, inland waterways, or because of climatic trends. Then there are the more global environmental problems to emphasize environmental interdependence: acid rain (from industrial emissions), depletion of the ozone layer in the atmosphere (from fluorocarbon use), and increased heating of the Earth (greenhouse effect increased by the burning of fossil fuels and abetted by deforestation). Radioactive fallout such as that from the Chernobyl accident, desertification (increasing at a rate of 6 million hectares annually)2, and poisoning of oceans

and other water masses diminishing their productivity (from runoff of pesticides, heavy metals and other toxic wastes) also impact on great areas of the Earth. The fragility of the total ecosystem sums from its parts. Make the parts operate under the aegis of environmental protection and the total unit, in this case the Earth, will retain its long-term population carrying capacity.

Omissions or errors in development planning that debase the environment are always more apparent in hindsight. Some active environmental groups focus on these high profile problem-ridden projects for various reasons without any citation at all to the numerous other projects funded by governmental agencies, commercial lenders, and development banks, that have achieved the aims of sustainable development, alleviation of poverty, and environmental protection, without incurring serious problems.

Heightened awareness of the importance of environmental management in natural resources exploitation has made leaders of developing nations and lender institutions realize that environmental issues and economic progress are inexorably linked in any development package. Although international lenders for major national projects can not dictate that a country must establish and follow environmental protection measures before funding is granted, pre-development planning missions can highlight the need for environmental management to achieve sustainable growth. Sustainable growth is understood by governments. Many of the LDCs have formed federal environmental planning and action offices. These send out field teams that monitor development projects and work through their governments to get adherence to the ecologically sound management norms established for a project. The use of geographical information systems has intensified in coupled economic development-environmental protection studies and will certainly continue to develop and provide important data bases and innovative interpretative methodologies for working with interrelated multisectoral problems in the future.

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GIS DEVELOPMENT IN TAIWAN

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ABSTRACT

For the past two years Taiwan has made significant progress in the development of geographic information systems(GIS). A number of government agencies and universities have been involved in securing GIS hardware and software, and in identifying areas of application. GIS software packages currently available in Taiwan include ARC-INFO, PC ARC-INFO, INFORMAP II, EMIS, and GEOMIPS. Areas of application range from regional planning to slopeland management to multipurpose cadastre. The development of GIS in Taiwan, however, is hampered by a lack of data base, a lack of coordination among users, and a shortage of human resources. Land use data and elevation data derived from 1:5,000 orthophotomaps are available in a digital format, and a digitization project is currently under way for land ownership data at 1:5,000. Data conversion is required for other types of data. Coordination among users is needed in developing the data base as well as in data access. Project managers who can organize GIS operations and assist in the long-term development of GIS in Taiwan are in short supply. The paper also presents a demonstration project on slopeland management.

1. INTRODUCTION

As a tool for storing, manipulating, and analyzing spatial data, geographic information systems (GIS) have been widely adopted by

government agencies, private companies, and universities in the United States and other developed nations. The technology has also spread, at an increasing rate, to other parts of the world. Since the success of a GIS depends on such factors as computer hardware and software, data base, and human resources, different countries have different experiences with GIS development. The purpose of this paper is twofold. First, it describes the development of GIS in Taiwan for the past two years. Secondly, it discusses several problems, which make GIS implementation difficult in Taiwan.

2.BACKGROUND

Taiwan is an island of 36,000 sq.km. (14,000 sq.mi., or about one-fifth of the size of the state of Washington) with a total population of 19.3 millions and one of the highest population densities in the world. Approximately three-fifths of the island is mountainous. Most farmlands are distributed on the lowlands along the west coast and along a rift valley in the east.

Since the 1960s Taiwan has experienced remarkable economic growth, and a structural change from an agricultural society to an industrialized society. This transition has brought about rural to urban migration, a rapid growth of major cities, degradation of the environment, changes of agricultural land use, and use of marginal agricultural land. Centralized planning has been an important characteristic of the Taiwan society. There are government agencies at the national, provincial, and local levels that develop, implement, and evaluate policies for economic development, agricultural planning, technological development, and so on.

Given the emphasis on planning, it is easy to understand the need for GIS in Taiwan. Although the concept of GIS had been discussed in meetings and symposia in the early 1980s, usually in conjunction with the technology of remote sensing, the first documented GIS project did not appear until 1985. Chang (1986) used GEOMIPS (a software package consisted of IDIMS, GES, and ERIS) to build a GIS for regional planning in Taitung.

The development of GIS in Taiwan has progressed rapidly for the past two years. A number of universities and government agencies have actively engaged in GIS projects, several GIS software packages have become available, and a variety of application areas have been identified.

3.GIS DEVELOPMENT IN TAIWAN

3.1 Participants in GIS Development

The development of GIS in Taiwan has been promoted primarily by universities and government agencies (Table 1). University

researchers represent the fields of geography, remote sensing, urban planning, transportation, and computer science. Government agencies involved are those responsible for the inventory and planning in agricultural and urban land use, and for the maintainance of land records. The two groups have often worked together through grants and contracts. Many university researchers and government officials have advanced degrees from U.S. universities; they maintain their contact with current developments in GIS through journals and professional meetings. The Taiwan government has also sponsored researchers for advanced studies in the U.S.

Table 1. Participants in GIS development

1. Department of Geography, National Taiwan University
2. Remote Sensing Research Center, National Central University
3. Remote Sensing Research Center and Department of Urban Planning, National Cheng Kung University
4. Department of Applied Mathematics, National Chung Hsing University
5. Council of Agriculture
6. Council for Economic Planning and Development
7. Land Administration, Ministry of the Interior
8. Construction & Planning Administration, Ministry of the Interior
9. Taiwan Provincial Food Bureau
10. Taiwan Provincial Department of Agriculture and Forestry
11. Taiwan Telecommunication Company
12. Taipei City Government

The private sector has also participated in GIS development. Most U.S. companies that market GIS packages and computer equipment have representatives in Taiwan. Besides promoting sales, these representatives have helped universities and government agencies in terms of system design. So far, no private companies have been engaged in research in GIS software.

3.2 GIS Hardware and Software

The availability of GIS software in Taiwan has improved significantly since 1986, when GEOMIPS was the only available package. The Department of Geography at National Taiwan University has ARC-INFO and EMIS operating on their MICRO VAX. GEOMIPS is available on a VAX computer at National Central University; it is expected that ARC-INFO will be installed on the same computer by the end of 1987. National Cheng Kung University is negotiating with ESRI for purchase of both ARC-INFO and PC ARC-INFO. National Chung Hsing University is getting PC ARC-INFO.

Taiwan Telecommunication Company signed a licensing agreement for INFORMAP II in 1986. Various government agencies are in the process of evaluating GIS software packages for their needs. The Land Administration of the Ministry of the Interior is considering packages from INTERGRAPH, SYNERCOM, and ESRI, and the Taiwan Provincial Food Bureau is interested in ARC-INFO.

Microcomputer-based GIS software packages have a special appeal in Taiwan, especially when a university or a government agency is at the initial stage of GIS development. Among the reasons for this appeal are: (1) prices of PC-based packages are lower than those of mainframe- or minicomputer-based; (2) Taiwan has a well-developed microcomputer industry; and (3) as microcomputers become more powerful with their late models, they may be adequate for some Taiwanese government agencies whose jurisdictions cover much smaller areas than their counterparts in the U.S. Of course, a network can conceivably be developed between a mainframe and PC's, in which data sets can be downloaded from the mainframe to a PC for independent GIS manipulations.

3.3 GIS Data Base

The GIS data base in Taiwan is very limited. A potential source of the data base is the series of large-scale photo base maps completed in 1982. Produced by the Agricultural and Forestry Aerial Survey Institute under the sponsorship of the Council for Agricultural Planning and Development(1983), this series covers the entire island with a total of 3,773 maps. The map scale is 1:5,000 for lowlands and hilly areas(3,209 maps), and 1:10,000 for mountainous areas(564 maps). The map information includes land use data, elevation, transportation, drainage, cultural features(e.g., public buildings and schools), and administrative boundaries(township, county, and city boundaries). The contour interval is five meters on 1:5,000 maps and ten meters on 1:10,000 maps. Map revision is scheduled for every six years for urban, well-developed, and consolidated farmland areas, and every ten to 15 years for underdeveloped and mountainous areas.

Land use data is the only type of data from the map series that is currently available in a digital form. Closely related to it is the digital elevation data produced by the Agricultural and Forestry Aerial Survey Institute at 1:5,000 and sampled at a 40-meter interval.

Taiwan Provincial Food Bureau has recently completed the digitization of land ownership boundaries for lowland areas, using 2,000 sheets of 1:5,000 maps as the source. There are other limited digital data files. For example, the Department of Geography at National Taiwan University is digitizing island-wide elevation, transportation, drainage, and boundaries from 1:100,000 topographic maps and a watershed data base in northern Taiwan.

3.4 GIS Applications

Table 2 lists areas of GIS applications that have been identified. Most of them involve cooperation of universities and government agencies and are in the initial phase of development.

Table 2. GIS applications

1. Comprehensive regional planning
2. City planning/urban and housing development
3. Agricultural land use planning
4. Slopeland management
5. Mass transit system in Taipei
6. Multipurpose cadastre
7. Management of public utilities

A demonstration project on slopeland management recently completed at National Taiwan University (Chang, Sun, and Chang,1987) is illustrated here as an example of GIS applications in Taiwan. The study area is located in the east coast of Taiwan, and covers 2,836 hectares of slopelands. Slopelands are defined by the Mountain Agricultural Resources Development Bureau as lands with elevation above 100 meters or lands with slope greater than 5%. Using the ARC-INFO package, the project prepared a data base consisted of land use, topography, soil, climate, drainage, transportation, administrative boundaries, land ownership boundaries, and population(Fig. 1 and Table 3). Two types of data analysis were performed. The first was a land use suitability study by comparing

the distribution of land use with that of land capability. Land capability was derived by using weighted factors representing the topographic variables(elevation, slope, and aspect) and soil characteristics(soil type, soil depth, and pH value). Through the land use suitability analysis, slopelands were grouped into three general classes: improper use, proper use, and under-utilized. The second analysis involved suitability studies of tea production and pineapple production based on the variables of topography, soil, climate, drainage, and transportation. Combining results from the two analyses, the project was able to make recommendations on tea and pineapple as alternative crops in under-utilized areas. Data sets on administrative units, land ownership, and population, although they were not used in data analysis, will be useful at the stage of policy implementation.

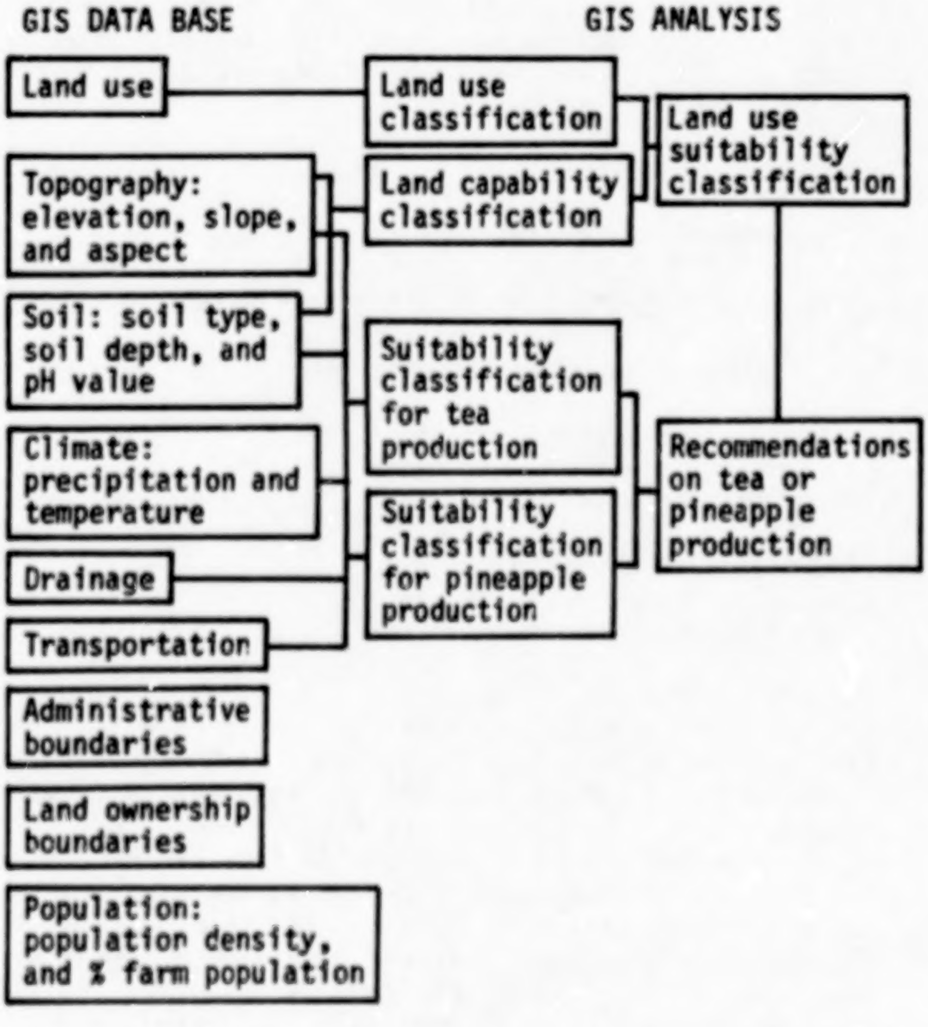

Fig. 1. A GIS for slopeland management in Taitung, Taiwan.

Table 3. Data, data source, and map scale for the Taitung GIS

Data	Data Source	Map Scale
Land use	digital data files	1:5,000
Topography	digital data files	1:5,000
Soil	digitized from maps	1:25,000
Climate	compiled from weather station data, and digitized from maps	1:400,000
Drainage	digitized from maps	1:5,000
Transportation	digitized from maps	1:5,000
Administrative boundaries	digitized from maps	1:50,000 and 1:100,000
Land ownership	digital data files	1:5,000
Population	digital data files	

4. PROBLEMS WITH GIS DEVELOPMENT IN TAIWAN

Although Taiwan has made significant progress in GIS hardware and software for the past two years, there are problems that make GIS implementation difficult.

4.1 Data Base

The data base is the foundation of a GIS. Taiwan needs to develop the data base quickly if the current interest in GIS is to be sustained. The large-scale orthophotomaps mentioned earlier can play an important role in this effort. At present, only land use data and elevation data are available in a digital form; the digitization of other types of data is therefore a urgent task.

The orthophotomaps are available only at 1:5,000 and 1:10,000, which certainly do not meet all the needs of different government agencies or universities. Land ownership is one example. Maps at 1:5,000 may suffice as the base map for farmland ownership, but they are not detailed enough for urban or well-developed areas. Another example is the coastal zone management project proposed by the Council for

Economic Planning and Development; it has been suggested that the project needs 1:1,000 maps.

The challenge therefore is to prepare different series of base maps in a logical order. Since the orthophotomaps have the map scales of 1:5,000 and 1:10,000, it will be logical to adopt other metric scales such as 1:500, 1:1,000, 1:100,000, and so on. In practice, this presents a particular problem for cadastral mapping. During the Japanese occupation of Taiwan(1895-1945), land records were compiled on map series of a different progression(1:600, 1:1,200, 1:4,800, etc.). These land record maps are still being used in some parts of Taiwan. It will require a special effort from responsible government agencies to convert land record maps to standard map scales in the future.

As more maps and data are prepared by different agencies, the enforcement of data quality and standards will be critical. At present, no agencies or committees are in charge of the task.

4.2 Coordination Among GIS Users

The present stage of GIS development in Taiwan is characterized by the efforts of individual universities and government agencies: first, to secure GIS hardware and software, and then, to prepare digital data files for specific projects. Cooperation between government agencies and universities is usually conducted on the project basis.

It will be a tremendous boost to GIS development if potential users can cooperate at a larger scale, such as the sharing of the data base. Soil data, for example, can be useful to researchers in comprehensive regional planning as well as those in slopeland management. It is a waste of time and effort if the same set of data is collected by two or more separate organizations.

Coordination is also needed among users within a large organization in terms of data access and networking. As an example, the Provincial Department of Agriculture and Forestry has field stations all over the island. It is important that the department develops a network so that the GIS data base can be shared by all field stations.

Competition between agencies and between universities is to be expected. However, it has to be set aside, at least temporarily, if GIS implementation is everyone's first priority.

4.3 Human Resources

A successful GIS operation requires hardware and software, data base, and, more importantly, human resources. Managers of GIS

projects must be familiar with data manipulation techniques and, at the same time, have the vision of applying the technology to real-world problems. GIS operations are also different in the sense that they often involve map layers representing a variety of physical and cultural data; the approach is therefore interdisciplinary.

The early promoters of GIS in Taiwan were physicists and engineers who considered GIS as an extension or application of remote sensing. Their interest was technical in nature. Only in the past several years, geographers, planners, and foresters have turned their attention to GIS and applications of the technology. Cartography has never been a recognized field of study in Taiwan. It is interesting to note that the current interest in GIS has resulted in a higher visibility of cartography, especially computer-assisted cartography.

There is a definite shortage of project managers in Taiwan who can organize and oversee different aspects of GIS operations and who can plan the long-term development of GIS. The Taiwan government has sponsored workshops and symposia on GIS, usually with speakers from the U.S. It has also sent university researchers and government officials overseas for advanced studies. The problem of human resources will improve in the near future, but it will take a longer period to cultivate "local experts" for problem-solving in Taiwan.

5.CONCLUSIONS

A number of government agencies and universities in Taiwan have explored the potential of GIS, have secured GIS hardware and software, and have identified general areas of application. They are now facing the problems of data base, coordination among users, and human resources. Efforts are being made in those areas. Taiwan's experience is certainly not unique. It just reinforces the simple fact--often overlooked by organizations in their ardent pursuit of GIS capabilities--that computer hardware and software alone will not produce operational GIS.

As Taiwan is moving ahead with its GIS development, several interesting topics are open to researchers. The first is the design of the GIS data base; the challenge is not only to develop the data base quickly but to meet needs of different government agencies. Second, as various organizations are acquiring GIS hardware and software for both mainframe and PC versions, it calls for careful planning so that an efficient network can emerge. The third is comparison between aerial photographs and satellite images as the source for land cover data. Because farmlands are highly fragmented in Taiwan, data resolution is a major concern. So far, aerial photographs have prevailed, but the situation may change in the future as the resolution of satellite images continues to improve.

Finally, the question is on the value of the GIS technology. Can GIS be a useful tool in a country that is vastly different from the U.S. in both the physical and cultural environments?

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GEOGRAPHIC INFORMATION SYSTEMS IN THE NETHERLANDS: APPLICATION, RESEARCH AND DEVELOPMENT

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ABSTRACT
In the Netherlands, the interest in geographic information systems for urban and regional planning purposes has grown considerably in recent years. At present, advanced systems have been installed in only a few places, and GIS research and development is confined to a small group of scientists. So far, most GIS projects have focused on software development and on exploration of GIS techniques. Analytical and planning applications have therefore usually been experimental or prototype in character. But as knowledge about the potential uses of GIS is spreading and prices of hard- and software are falling, people have come to realize that we are at the brink of a widespread utilization of the technique. This has generated a number of more large-scale GIS research and development programs, in academia as well as in practice.

1. INTRODUCTION

Environmental management is a longstanding scientific and practical speciality of the Netherlands. Some five centuries of struggle with the sea and numerous rivers and a long history of intensive urban and agricultural land utilization have generated an accumulated expertise in land and water management and in urban and rural land use planning. The Dutch are therefore alert to new technology that can be employed to improve environmental planning and management. Geographic information systems do seem to represent such a new technology. At first sight, the possibilities for easy manipulation of georeferenced data seem to mean a true breakthrough for the environmental sciences. As with other technical advances however, much research and development effort has to be mobilized in order to exploit all the possibilities for day-to-day practical work. Therefore, the introduction of GIS in practice should be accompanied by both fundamental and applied research in geographic information processing. It is this association between practical applications and research and development that will be dealt with in this paper. We restrict ourselves to the situation in the Netherlands and give special emphasis to analytical and planning applications of GIS.
The first part of the paper gives an overview of implementations of geographic information systems in the Netherlands. Next, recent research efforts will be reviewed. Finally, we will deal with research needs that have been identified and research programs that are emerging.

2. GIS SYSTEMS IN THE NETHERLANDS

In a broad sense, geographic information systems can be defined as all activities dealing with computer-assisted processing of georeferenced data. In a more strict sense, the term GIS should be reserved for hard- and software-configurations that are explicitly designed for interactive geographic information processing. With respect to these systems, two

main types can be distinguished (Ottens & Harts 1987):

a. Land Information Systems (LIS)
   These cartographic drawing and database systems are primarily designed for the handling of detailed map information with high levels of geodetic and cartographic accuracy. These systems are often special versions of computer-aided design packages, which work with vector data. As databases are large, implementations are mainly on supermini and mainframe computers. Only very recently, also implementations on supermicro-computers and workstations have become feasible. Intergraph, Computervision and Sicad are well known examples of this type of systems;

b. Analytical geographic information systems (GIS)
   These systems deal with more generalized and small-scale map information, and are developed especially for the combined spatial manipulation of map and attribute data. The origin of these systems can be found in geostatistical analysis and automated thematic cartography. Normally, the software is able to process both vector and raster data. Minicomputers used to be the standard hardware for these analytical geographic information systems, but gradually powerful microcomputers and workstations are gaining importance. Arc/Info and MOSS/Deltamap are examples of relatively widely used analytical packages.

Apart from the two broad types of GIS just mentioned, there are a number of closely related information systems in which geographic data also play an important role.
Somewhere between the cartographic database systems and the analytical systems, we find processing systems for earth images. These systems combine large databases with powerful image processing capabilities. As a consequence of the nature of the data, these remote-sensing systems are exclusively restricted to raster processing. Because of the demanding data-storage capacity and processing power, image processing systems tended to be large and expensive. However, small but powerful computer systems are capturing the market in this field as well.
Finally, navigation systems should be mentioned. As is the case with remote-sensing systems, military research has been of vital importance for their development. This type of systems, which use vector data, are employed for monitoring, guidance and control of all types of traffic flows. Depending on the scale of the application, both large and small systems can be found.
Although several types of GIS can be distinguished, it is important to stress that there is a strong tendency towards convergence, leading to general purpose geographical information systems, which run on small graphic computer systems.

The introduction of land information systems in the Netherlands began earlier and has progressed further than the implementation of analytical GIS systems. Several interactive graphic systems have been installed during the last decade in institutions of higher learning (like the International Institute for Aerospace Survey and Earth Sciences ITC in Enschede and the Universities of Wageningen, Utrecht and Delft) and at several public agencies (like utility companies and municipal land management departments). Some software manufacturers have also entered the market for cartographic CAD systems. A recent major development is the automation of the cadastral system in the Netherlands.

Until very recently only the National Physical Planning Agency of the Ministry of Housing, Planning and Environment and the Department of Geography of the University of Utrecht possessed of a full-fledged mini-computer based analytical geographic information system: an Arc/Info/-Prime and a MOSS/Autogis/Data General system respectively. At the ITC in Enschede, the Agricultural University in Wageningen and the Institute of Spatial Organization INRO/TNO in Delft quite a bit of work has been done on the development of special-purpose geographic information systems. The USEMAP, MAP2 and SALADIN packages resulted from these research efforts. The software is operational at the respective development sites and a limited number of packages have been sold to third parties.
At the moment there is great interest in acquiring analytical systems, especially among geography, planning and environmental science departments of universities, provincial and municipal planning departments, and among land, water and resource management agencies. Arc/Info systems have been ordered by the universities of Wageningen, Utrecht, Nijmegen, the INRO/TNO and the ITC. The Deltamap package has been bought by the University of Utrecht and purchase is under consideration by several other institutions. It can be expected that a few dozen commercial systems will be sold in the coming years.

There are some five installations of remote sensing systems in the Netherlands. With respect to commercial navigation systems, the research and development activities of Philips (CARIN system) and Tele Atlas (network databases and routing software) should be mentioned.

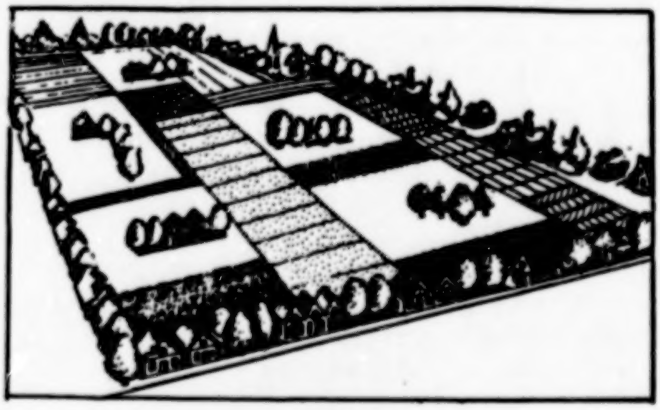
3. GIS RESEARCH AND DEVELOPMENT IN THE NETHERLANDS

Research and development with respect to analytical geographic information systems is carried out at a few centers: the National Physical Planning Service, ITC, INRO/TNO, and the universities of Wageningen and Utrecht. In this section we will give a short impression of the type of projects that have been completed.

GIS research carried out at the National Physical Planning Service aims at improving the use of their Arc/Info system as an important tool for national physical and environmental planning and monitoring (Scholten, Drewe & van der Velde 1987). Periodically the Minister of Physical Planning presents long- and medium-term national physical plans and spatially relevant sector plans with general goals and guidelines. They function as a framework for urban and regional planning for provincial and local governments. The introduction of GIS in the organization did cost a lot of time. People had to be trained, existing cartographic and statistical databases had to be converted to formats that can be used by Arc/Info. The implementation process is accompanied by several pilot studies. Two of these studies will be reviewed briefly, to give an indication of the type of research that is being undertaken.
The first example is a GIS study of changes in the visual scale of landscapes in the Netherlands (Zevenbergen & Scholten 1987). It was hypothesized that differences in landscape types are disappearing, or at least diminishing. The open landscape, characteristic of the western and northern parts of the country, is threatened by urbanization, the construction of wind buffers, road-building, etc. In the eastern and southern parts of the Netherlands, mainly areas with a more closed

landscape, rationalization of farming activities and, as a consequence, reallocation of farmland is opening up the landscape. GIS was used to test and quantify these perceptions.
An existing database from a recent landscape study was used as a starting point. To each of 10,526 grid cells (2 x 2 kilometer = 1.25 x 1.25 mile) covering the country, several landscape indicators were added as attributes. For instance: size of the biggest enclosed landscape element, number of point elements (farms, small bushes, etc.), length of visual line elements (ribbons of houses, trees, etc.) and size of the parcels (figure 1). In a sample of 284 grid cells the same information was gathered on the bases of old topographic maps of 1850, 1930 and 1960.

Figure 1: Landscape elements



Source: Zevenbergen & Scholten 1987

GIS appeared to be a useful instrument for constructing landscape types through interactive modeling, using different combinations of attribute criteria. In order to identify landscape changes, historic landscapes were simulated from the sample data. In this case, mainly database and retrieval functions of GIS were used.

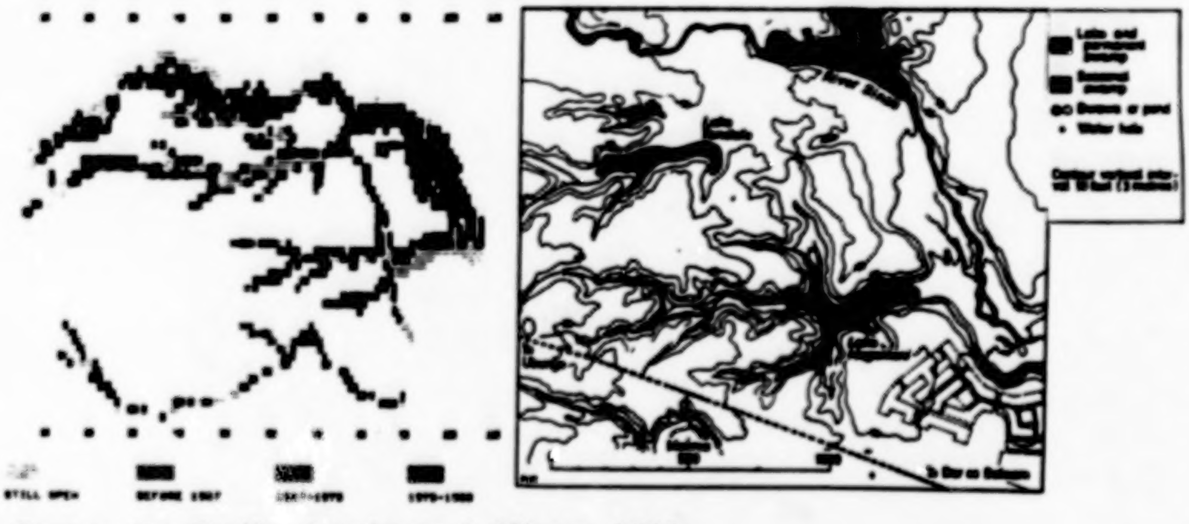
The second example is a study of the land use consequences of future agricultural developments (Padding 1987). Due to the overproduction in agriculture in the European Economic Community, agricultural land use is likely to reduce or change considerably in the near future. The pattern of land use change will differ depending on assumptions made regarding factors that influence agricultural land use. These factors include policy decisions and possibilities for multiple and alternative land use (recreation, afforestation, urban expansion, etc.). With the use of GIS, all relevant criteria were translated into maps; with overlay techniques, the land use consequences of combinations of criteria could be calculated and mapped. Figure 2 gives an example. The main problem of this kind of application is to acquire the right data at the required geographical scale.

The International Institute for Aerospace Survey and Earth Sciences (ITC) in Enschede has a relatively long tradition of GIS research and development (Linden 1985; De Bruijn, Lutchman & Sliuzas 1986). GIS

Figure 2: The intention to combine recreational and agricultural land use and its potential in terms of agricultural production.

activities started more than ten years ago. Due to the function of this Institute, studies are often a combination of aerial photography, remote sensing and GIS, and most applications deal with developing countries (Juppenplatz, Leekbhai & Chanond 1985).
The Institute developed a grid-cell GIS package, which runs on a mini-computer configuration. It is called USEMAP. Recently the decision was taken to also install Arc/Info.
Several publications give an overview is given of possibilities for (cartographic) computer applications for research and planning purposes. Of particular value are studies in which sequential aerial photography is used (De Bruijn & Sluzias 1985).
An example of this type of projects is an analysis of the development of a large squatter area in Dar es Salaam (De Bruijn, Lutchman & Sliuzas 1986). In this study, urban sprawl, infill and reconstruction were related to natural conditions in the district. Figure 3 gives an example of the kind of results obtained. The problem in this case was to link map information with census data. This turned out to be impossible.
In a study contracted by the Dutch National Physical Planning Service, the same line of research was pursued (De Bruijn 1981). On the basis of aerial photographs taken in 1965, 1975 and 1979, of South Limburg, the

Figure 3: Geomorphology and earliest development on less suitable lands of the Manzese area Dar es Salaam.



Source: De Bruijn, Lutchman & Sliuzas 1986

most southern part of the Netherlands, land use changes were analyzed. One of the major results of this study was the construction of a stability map, indicating the relative sensitivity of the various rural areas to further urbanization.

Most ITC projects are carried out in developing countries in cooperation with local planning agencies (Juppenplatz, Leekbhai & Chanond 1985; Lutchman 1984). A further expansion of GIS research, especially the combined use of GIS and earth image processing techniques, is one of the research goals of the ITC for the near future.

The Agricultural University in Wageningen is another center of GIS activities in the Netherlands. At this research facility, the Yale/Harvard MAP package was further developed and adapted for use on personal computers. The main goal of the GIS projects in Wageningen is to develop prototype applications for environmental planning, three-dimensional landscape design, and digital terrain modeling. Several studies have been completed (Van den Berg & Blom 1985). The majority of the planning projects are detailed applications in small regions.
In an area just east of The Hague (Rip 1985), the use of GIS for physical planning purposes was simulated and compared with the situation wherein no GIS was used. The main conclusion was that the use of GIS requires a different way of thinking on the part of planners. Planning goals and restrictions have to be 'translated' into maps. This also means that a lot more has to be quantified and converted into square meters. Perhaps this is a general problem of GIS. Politicians prefer to use fuzzy concepts like 'more' and 'less' and try to avoid precisely quantified statements.
There are strong ties between university departments and national rural and agricultural research institutes in and around Wageningen. Two of these institutes, De Dorschkamp (applied landscape research) and Stiboka (soil mapping), both of which have considerable experience with geographic information processing, will in the near future be combined into one center.

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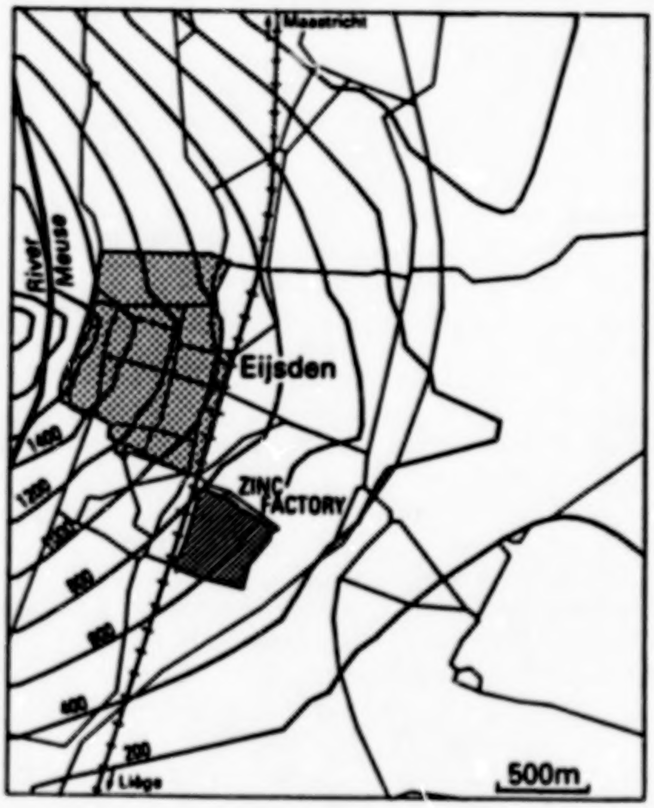
The Institute of Spatial Organization INRO/TNO in Delft has also developed a GIS package, SALADIN (Van Est, De Vroege & De Jong 1986). This personal computer-based package uses the line-segment method to record digital map information. It was developed especially to store and selectively retrieve address information and to produce thematic maps. There are no buffer and overlay commands available. The package is used by several municipalities and at a number of universities.
With the SALADIN package various research projects were carried out, both in the Netherlands (for instance in the municipality of Rotterdam) and in Indonesia (Van Est & Versluijs 1985). These studies are often a combination of an application and a further development of SALADIN.

At the Department of Geography of the University of Utrecht, GIS has become a major research topic. Physical and human geographers and cartographers are working together in one research group on GIS development and GIS applications. In the past three years, the emphasis has been on exploration and evaluation of the applicability of GIS for geographical research and for urban, regional and environmental planning.
One of the goals is to disseminate knowledge and experience on the possibilities and limitations of GIS technology (Burrough 1986a, Burrough 1985; Harts & Ottens 1985; Ottens & Harts 1985). In the Netherlands geographers hold a fair share of the jobs in the planning practice. Funded by the University of Utrecht and the Ministry of Education and Sciences, the Department of Geography was able to start the first GIS education and research project some three years ago. The project included the installation of the GIS package AUTOGIS (the MOSS family of GIS software) on Data General mini- and desktop computers. The MOSS software is public domain. Installation and training was provided by Autometric Inc., Fort Collins, Colorado. This fall, the Autogis/Data General system will be replaced by Deltamap/Hewlett Packard systems and an Arc/Info installation on an IBM PS/2 is envisaged for early 1988. A number of raster packages, including MAP, CRIES, IDRISI etc., is used for educational purposes and student projects. Software development has mainly concentrated on the integration of geostatistical and geomodelling tools with GIS applications.

Systematic development and evaluation of GIS applications is the main goal of the ongoing research project (TOEPGIS). All pilot and prototype studies were carried out in cooperation with external counterparts (Toppen & De Jong 1986; Toppen & Van Oort 1986; De Jong & Toppen 1987). In this way practical experience could be gathered and expertise about the GIS technique could be passed on to government planning agencies. A few examples will be reviewed.

The possibilities of GIS for the registration of local plans were surveyed in a study financed by the National Physical Planning Service (Scheele & De Jong 1984; Scheele & De Jong 1986). As a pilot project, all local plans of a few municipalities were digitized and information about the status and procedures of the plans was added in an attribute file. It could be concluded that GIS is a very elegant tool for the registration of this kind of information. But digitizing and subsequent updating of all the plans means a large investment in time and money -- the more so when there are marked differences in size and detail of local plans-- so a selective approach was recommended.

Figure 4: Interpolation map of zinc concentrations in the topsoil.



Source: Rang, Okx & Burrough 1987

In another project, in cooperation with the planning department of the province of Limburg, problems of pollution by heavy metals in the valley of the river Geul were studied (Leenaers, Rang & Schouten 1987). There are various sources of pollution: local mining activities, local industries and old sediments. In this project, geostatistical interpolation techniques for mapping soil pollution were developed and used (Rang, Okx & Burrough 1987, see figure 4).
The pollution patterns could only be clearly discerned and evaluated after the geostatistical techniques had been developed. The resulting maps give a good indication of the general geographical distribution of the pollutants, but are still insufficient for determining whether or not individual land parcels match environmental health standards. However, the maps do form an excellent basis for preparing a program of detailed sampling. Within this study, other aspects of the pollution problem, for instance ground water quality, were also studied (Schouten, Okx & Rang 1987).

Each year, the provincial government of Utrecht issues a report on the capacity for housing construction within local land use plans. Until last year, this report contained primarily a series of large tables. The purpose of a project contracted by the Provincial Physical Planning Department was to look at the possibilities of GIS for a more accessible presentation of the capacity figures by means of maps and for a confrontation of proposed building sites with the zoning recorded in local plans (Toppen 1987, Toppen 1986). The presentation of the capacity information in the form of maps was a success and will be continued in

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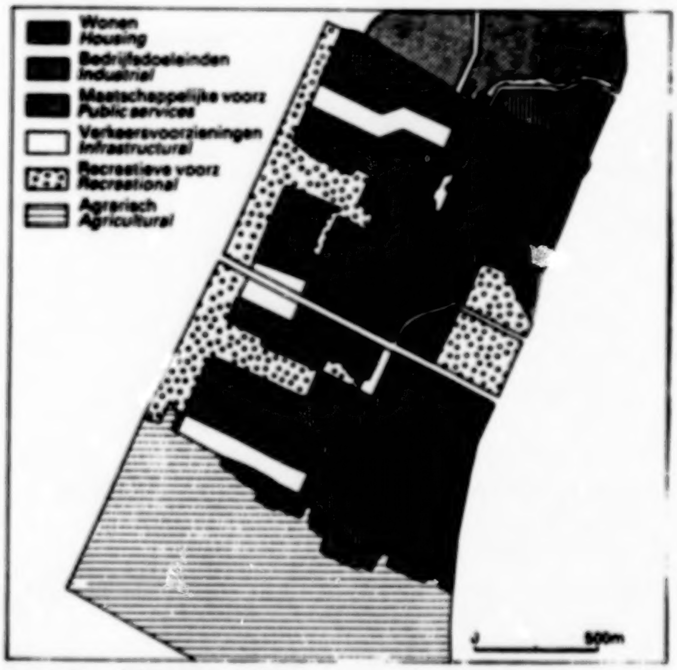
Figure 5: Zoning plans within building sites in Veenendaal.



Source: Toppen 1986.

the future. The cartographic comparison (overlay) between proposed building sites and existing zoning plans was interesting but turned out to be a tedious digitizing task, particularly since no accurate base map standards were employed. In the production phase of the project, only the building sites were digitized. The attribute file contains information on quantitative and qualitative aspects of the building capacity.
A more general conclusion from this project and related studies is that the a priori selection of the software tools to be used, a CAD-system, a mapping package or a GIS, is crucial to the success of a project.

Together with the Authority for the IJsselmeer Polders, the Department of Geography completed a study to explore the way in which geographical information systems could be useful in developing land use alternatives for the fifth polder, Markerwaard (Smeenk, Toppen & Harts 1987). The construction of this polder is still under discussion.
Suitability maps were available for different types of land use. They were made on the basis of soil surveys of the lake bottom. The demand for twelve different types of land use was quantified. These types of land use were ranked by the Polder Authorities according to officially accepted policy guidelines. Some additional conditions had to be added: minimum cluster size (to avoid numerous small units) and minimum and maximum distances between land use types (for instance, labor-intensive agricultural activities in the proximity of urban land use, recreational area not near bulb-growing to avoid plant diseases, etc.).
The empty polder was filled in a stepwise procedure, according to the rank order of land use priorities. The suitability map, conditional maps and a map with land use that was already allocated in a previous step formed the input information for each step. As the Autogis package does not contain optimization procedures, human intervention was necessary at each step.
The GIS analysis demonstrated that it was impossible to allocate all

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kinds of land use without violating the criteria. The demand for sandy grounds was too great. GIS proved to be a useful instrument in constructing a transparent procedure for the allocation of land use activities.

4. A GIS RESEARCH PROGRAM

In 1985, the Ministry of Education and Sciences commissioned a project, which included a trend report and a programming study, to prepare a GIS research program. These activities were part of a large government program to promote informatics in the Netherlands. The project concerned was conducted by a team of experts from the universities of Utrecht, Wageningen, Delft and the ITC (Burrough 1986b).

Based on an inventory of user requirements and wishes and a survey of technical developments and possibilities, a number of urgent research themes were selected. These themes are: a rethinking of adequate GIS data structures, the introduction of functional relations in spatial data sets, the integration of dynamic spatial modeling modules in GIS, the development of intelligent geographic information systems, the problem of specific versus general-purpose systems, data quality and its consequences in data processing, the introduction of fuzzy logic in GIS methodology and the implementation of new soft- and hardware technology like: advanced information analyses, relational data bases, expert systems, advanced programming tools, parallel and distributed processing and networks.
A research program entitled "Quality and dynamics in GIS" was proposed. This program should consist of four sub-programs: spatial dynamics, data integration, quality of data processing and new technology.
The first sub-program will deal with developing modules for GIS analyses of geographical interaction and change. With respect to data integration, the use of aerial photographs and remotely sensed and preprocessed earth images as data sources for GIS applications is considered of vital importance. Research into mathematical confidence connected with GIS analyses and the introduction of the fuzzy logic methodology into GIS commands form the foremost interest in the third sub-program. Finally, the development of intelligent user interfaces and of expert systems to support GIS applications are the main "new technology"-research items.

The research program will be gradually implemented at the major GIS research centers in the Netherlands. Funding, however, has to come from different sources, so adjustments will have to be made. An important initiative is the proposed national center of expertise for spatial information processing. This center, an institution with the task to support and stimulate spatial informatics, will bundle all GIS expertise in the Netherlands and will provide potential GIS users with this expertise through the academic research network SURFnet. In the next five years SURFnet will become a full-fledged computer network for scientific research according to international standards like OSI and ISDN.

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NATURAL RESOURCES

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"UNDER THE RAINBOW"

GIS AND PUBLIC LAND MANAGEMENT REALITIES

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ABSTRACT

GIS technology has now achieved a popular culture status of the buzzword (the term -- 'McGIS'-- comes to mind). A real and tragic problem lay in naive use of eloquent Geographic Information Systems' to solve trivial or intractable non-spatial problems. Several projects illustrate questions that were well asked and answered by a GIS; how policy makers' attitudes towards GIS have changed within the agency; and, how the DNR's use of GIS technology has developed.

1. INTRODUCTION

The real power of Geographic Information Systems (GIS) technology lay in improving our abilities to integrate

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complex sets of data over highly variable dimensions of space and time. Paradoxically, while we have the technical ability to do far more than ever before, the substantive questions politicians and agency administrators ask GIS' personnel to solve often have not really gotten any better, deeper, or that much more pragmatic.

The Minnesota Department of Natural Resources has a long history of involvement (since the 1930's) with geographically-oriented data. We intensively use computers of all types to bring together the necessary information to address many of the recurring management problems of public lands. But none of this has come to pass overnight, and some of our history might be instructive. I am going to briefly relate some of that history, as well as of some of our GIS accomplishments.

2. MINNESOTA'S GIS

Minnesota's GIS, simply put, is the Minnesota Land Management Information System (MLMIS), maintained by the Land Management Information Center in the State Planning Agency. It is a grid-cell system based on the forty-acre parcel of the U.S. Public Land Survey (PLS) system.

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MLMIS was only possible because of two activities. The first was a unique 1963 statute passed by the Minnesota Legislature dedicating monies for outdoor recreation projects; thereby, creating a bipartisan legislative commission to administer these special funds. The second is primarily the work of one man, John Borchert, and his associates.

In short, Borchert conceived of, promoted and has consistently supported MLMIS. He was responsible for key agency and legislative actors accepting the ideas and promises of a statewide GIS. Because of his presence and interests, diverse parties became actively involved (both as contributors and as staff) from over a dozen academic departments and state agencies in the establishment of MLMIS.(1)

Borchert was able to parlay Minnesotan's great concern over the degradation of its lakes as recreational and residential resources in the 1950's and 1960's into a statewide information system by the 1970's.(2,3) The lakeshore study findings substantiated both previous policy studies and media reports. This crucial investment in geocoding some 40,000 lakeshore parcels was quickly expanded into a statewide land use map based on forty-acre parcels (with some 1.4 million parcels).

MLMIS has gone through two major transitions. It has gone from being an experimentally funded university project to a state agency. It also has gone from being a purely research and devlopment operation to a production service bureau. (It maybe going through a third transition from a pure service bureau to that of a diverse consulting service that allows for a concentration of technical and personnel resources for activities requiring critical masses of each.)(4)

3. DNR AND MLMIS

Originally, the DNR's use of MLMIS centered on merely creating basic maps and crosstabulations of selected resource characteristics (e.g., roads, water orientation, forest cover types, land ownership, etc.) on a county by county basis. The bulk of the work done with the system used exclusively its own data. We have gradually gotten away from such a dependent use of the system to collecting original geographic data (from recreational surveys, hunting and fishing harvests, etc.) at varying scales and use the system to demonstrate the geography of the results of complex analyses. More recent and illustrative activities include:

3.1 Suitability

In the early 1980's, state budget deficits were severe, and thet state legislature proposed to balance the budget by selling off the state's land holdings (some 5.6 million acres). In response to this proposal, DNR asked for funds to study these lands in terms of their management implications and natural resources.

After four years, we concluded that state lands with the highest real estate values were either purchased, had substantial existing investments, or were specifically prohibited from being sold by the Legislature. Also, when we had finished with the project, we had greatly expanded the volume and availability of geographic data. We had completed a number of statewide resource assesments - for the first time providing a comprehensive view of many resources (e.g., forestry - timber and mill accessibilities, recreational activities and settings, human population distributions and accessibilty to recreational resources). We also had made substantial converts of extremely skeptical managers of GIS data from working closely with them.(5)

3.2 Land Exchange

The DNR engages in land exchange with its citizens and other units of government. Traditionally, a number of

detailed tables have been created to describe the resources and resource settings of the involved parcels. These listings tend to be quite lengthy, and quite difficult to comprehend. We improved the basic job of balancing an exchange by developing a series of maps and statistical graphics (i.e., pie and bar charts, etc.) that describe individual parcels' resources, yet also place these same parcels in their appropriate statewide, regional, and local contexts.

3.3 Wildlife

The Section of Wildlife's furbearer program needed a way to assess aggregate changes in the geography of registered furbearer (i.e., bobcat, lynx, marten, fisher, and otter) trapping/hunting harvests. On a shoestring budget, we took their harvest data (collected at the township level), and created a yearly harvest atlas series for each species. We also created a statistical graphics report for program manager's to use in understanding the effects of both statewide and more localized harvest trends and locations.

3.4 Recreation

In 1978 and in 1986, the DNR administered general population surveys regarding Minnesotan's outdoor recreational preferences (for 60 some activities) in

order to assess precisely where residents go and what they spend on recreation. We have created an entire atlas of current and projected growth for each of the surveyed activities, as well as a data base that allows us to develop economic impact estimates for almost any area of the state.(6)

Minnesota's lakes are an important resource for outdoor recreation, especially for tourism, yet not all of the state's lakes are equally attractive to recreators; some lake settings are far from cities, relatively isolated from roads, and have ecological characteristics not highly valued. Thus, highly variable patterns of shoreland recreational development are produced because of the interplay of cultural and ecological features. Based on actual development data, we created a residential development potential model for lakeshore lots. The model has been accurate enough that a private development company acquired the data and now uses a variant of the model for locating and describing second home lakeshore properties.(7)

4. GIS REALITIES

Kierkegaard has said that we live in an age of advertisement. It seems appropriate that Christie's

recently sold an idea for a painting called - "Ten Thousand Lines Ten Inches Long, Covering the Wall Evenly". It seems our version of that painting would be something like "Millions of Spatial Variables Infinitely Dense, Covering all Possible Policies Evenly".(8)

I feel very uncomfortable with the idea that the discipline of Geography is entering a --'McGIS'-- phase of promotion; i.e., where the idea of a GIS has more value than the effort needed to build and maintain it. This attitude would have been fatal in Minnesota.

Minnesota's GIS was created in order to provide the state legislature with some basic information. An important fact often forgotten is that MLMIS was designed to be a public policy or legislative GIS; its resource data support policy, and not pure research objectives.

Borchert's emphasis always has been to produce project reports aimed at the topical interests of legislators on economic and land use subjects. His ability to focus on real resource issues is responsible for developing overall confidence in both MLMIS and its staff. Their pilot studies have developed specific techniques and processes at minimal investment risk. And, while the products of these activities have not always been highly

visible, they have often been essential material directly affecting governmental policies and actions.(9)

4.1 Political vs. Politicized

Minnesota's GIS successes have been largely due to being able to freely answer all questions asked, and provide information to all interested parties. We do not actively make political decisions for any politician. Instead, we provide political decision makers with as many options as possible. Our practice is to distribute, as widely as possible, every key data set involved in our work.

4.3 Lack of Understanding

What do you do when agency heads use an elegant GIS to solve spatially trivial problems? Or, they neither have the time nor energy to digest the material you produce for them (causing them to misunderstand your analyses)? Also, what can you do if your clients truly see maps as <u>photographs</u>, and not the result of complex intellectual and technical processes?

Some MLMIS projects have been correctly attacked on the grounds that the display capabilities are often much more powerful than the data. One critic likens these projects to putting "turbocharged V-8's in golf carts".(11) The

real issue is not that our display techniques should be crippled, but that the data, no matter how it is displayed, must be understood for what it is and means. A more appropriate story is that one does not take a Testarossa out on a run across Baja.

A hot topic is to how educate potential high-level users of GIS services. Most policy makers I know operate with different logics, standards, and language than their technical advisory personnel. A particular problem is that geographic data and analysis techniques often take time to adequately comprehend - precisely two commodities that most of these people lack. A partial solution of ours is to tell them what not to do with the data, and get their trust.

Finally, a survivable effort must embrace and understand change as best it can. In twenty years, MLMIS has gone from being a revolutionary concept, to a secured bureaucracy, and has become engulfed again in a second revolution of software/hardware and personnel developments. Anyone who manages such efforts must be willing to completely rethink their activities and rationales on a fairly frequent basis.

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INCORPORATING GIS METHODS INTO THE NATURAL RESOURCE MANAGER'S TOOLBOX: LESSONS FROM THE RHODE ISLAND GIS PROJECT

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ABSTRACT

The ultimate objective of the Rhode Island Geographic Information System Project (RIGIS) is to make GIS data processing an integral part of the effort to protect and manage the State's natural resources. To meet this objective, the Rhode Island Department of Environmental Management (DEM) initiated in 1985 a cooperative agreement between DEM and the University of Rhode Island (URI) to establish a statewide GIS database. GIS software (ARC/INFO) and the necessary hardware were purchased and the program became operational in January 1986. Data collection, data entry prioritizing, and application design are done by DEM staff. Data entry, analysis, and output production are done by University personnel. During the first 24 months of the project we have identified a number of challenging issues incumbent in meeting our ultimate goal. Our experience with these issues should be of value to new GIS sites or planned GIS installations. Specifically, we will address the following: 1) project management, 2) application prioritization and application design, 3) program funding, 4) pros and cons of using a graduate and undergraduate student data entry work force, 5) communication among program managers and technical staff, 6) training needs, 7) the implications of map scale and accuracy to application design and product development, 8) resolving the need for long-term database development versus the need for rapid turnaround product generation, and 9) the challenge of mobilizing the technical and analytical resources of a regulatory agency and an academic institution.

1. INTRODUCTION

In this paper we will describe why the Rhode Island Department of Environmental Management felt it necessary to make Geographic Information System data processing an important part of its analytical toolbox, why an academic institution felt it important to enter into a cooperative state/university GIS project agreement, how the GIS system was implemented, the kinds of applications in which the GIS has played a major role, and the organizational/technical challenges that face planned or developing multi-user GIS projects. We will identify the payoffs as well as the problems we have experienced.

We are writing this paper for states, municipalities, governmental agencies, or large companies that are considering implementing a GIS division, or have recently done so. The challenges and returns we identify are probably common to any large GIS program. Hopefully, future projects will benefit from our experience.

2. A BRIEF HISTORY OF THE RHODE ISLAND GEOGRAPHIC INFORMATION SYSTEM (RIGIS) PROJECT

In this section we will describe why the Rhode Island Department of Environmental Management (DEM) and the Department of Natural Resources Science (NRS) at the University of Rhode Island (URI) formed a GIS partnership, how the cooperative effort was initially organized, and how it was implemented.

2.1 The Need for GIS Capabilities at DEM: Modern Problems, Modern Tools

The Rhode Island Department of Environmental Management was created in 1978 by combining environmental protection programs from the State's Department of Health with the resource and land management functions of the Rhode Island Department of Natural Resources. The legislation creating DEM was similar to that passed in a number of other states in the late 1970's with the purpose of treating environmental issues in a comprehensive and coordinated way. But over the last ten years, Federal and State Governments have added new programs and new layers of regulation to deal with each newly discovered environmental threat. As programs became more complex and focused, they became isolated and uncoordinated with other environmental efforts. It has become increasingly difficult to

understand and manage the rapidly growing volumes of data in each area of concern let alone for the environment as a whole. It has become painfully clear that ecosystems and human health can only be protected from environmental threats in a holistic way. Anything short of this is likely to only move risks from one place or population to another.

As GIS technology developed, DEM's management saw its use as an opportunity to resolve several key problems in managing the State's environment. These include:

1. By converting complex data into map images, it should be possible to identify environmental trends and threats at early stages.

2. Data from different sources such as programs to regulate landfills, protect groundwater, protect surface water, keep record of industrial chemicals, and monitor air pollution might be combined in map overlays to identify regions of potential environmental concern.

3. Environmental and health data might be combined in map form to identify potential patterns of disease caused by environmental factors.

4. The graphic capabilities of GIS could present complex environmental trends in a way that would be understandable to elected officials and citizens.

In 1984 DEM hired a consulting firm to evaluate the feasibility of initiating a GIS project within the agency. The consultants determined that DEM did indeed have a need for sophisticated GIS data management and analysis capabilities and recommended that, based on DEM's needs, the ARC/INFO software product (Environmental Systems Research Institute, Redlands, California) be purchased. In 1985, DEM provided a grant to the Department of Natural Resources Sciences at the University of Rhode Island to begin development of a statewide GIS database. Further details of the consultant's report and the procurement process are given in Forkey et al. (1986).

DEM has now spent two years using GIS data processing methods. The Groundwater Division and the Narragansett Bay Project (a 5 year, EPA funded assessment of Narragansett Bay) at DEM have made extensive use of the system and will continue to do so. The GIS has made it

possible for DEM to provide essential groundwater data to towns for their planning councils. Scientists working on the Narragansett Bay Project use GIS-generated images for data synthesis and reporting applications. GIS products have been used to evaluate the environmental impact of proposed landfill sites and highway upgrades. As different divisions within DEM grow more aware of what the GIS Concept represents, plans are being made to incorporate new datasets into the system and to broaden its analytical potential. Finally, DEM has found that the GIS has been an effective rallying point for cooperative data sharing among DEM and other state agencies. As the database develops, as GIS hardware is brought to the operating divisions and connected with the URI facility, and as DEM staff become more proficient in using the system, we anticipate that it will become a central tool in the management of Rhode Island's environment.

2.2 The Need for Incorporating GIS Capabilities into the Academic Arena

The University of Rhode Island is a medium-sized university (12,000 students), and being a land-grant institution, recognizes its triad mission in the areas of teaching, research, and public service. As The State University, URI recognizes its obligation to provide students training in the use of state-of-the-art tools for assessing and evaluating complex contemporary issues.

Many of the traditional academic programs at URI, whether they be in the biological, physical, social, or economic sciences, rely on spatial analyses, or at least spatial presentation of data. Such diverse academic departments as Zoology, Botany, Geology, Natural Resources, Management Sciences, Community Planning, Resource Economics, and Geography have expressed the need to incorporate GIS methods into their teaching and research programs. GIS analysis is a modern tool to use on contemporary issues and the University is committed to educate its students in the use of these tools.

The University, in its faculty, staff and students, has a great deal of expertise in resolving complex problems in natural resource management. The Rhode Island Department of Environmental Management is mandated to manage and protect the State's environment. The combined resources of DEM and URI make for a very powerful force in solving environmental problems. Both agencies (DEM and URI) realize that cooperative projects are a cost-effective means of fulfilling

each institution's responsibilities. The GIS Project is not the only cooperative program between a state agency and the University but it is one that clearly demonstrates the need for and the value of pooling resources. It can become a critical interface between academic expertise and research with day to day government activities.

The Department of Natural Resources Science (NRS) at URI trains students and conducts research in the areas of groundwater management, soil science, forestry, wetlands, and wildlife. There is a heavy emphasis on applied research in the NRS program. This department was an ideal place to begin development of the GIS project. Its faculty and students were well-versed in natural resource management concepts and spatial analysis of geo-referenced data. The GIS would permit integration of the different areas of research within the department.

The relationship between DEM and URI is a complimentary one. DEM had the data and financial resources to initiate the RIGIS program. URI had technical and computer resources that were needed for the project. The benefits of a pooling resources to begin a state-wide GIS processing facility were clear.

2.3 The Implementation of RIGIS

In September 1985, DEM and NRS signed a two-year cooperative agreement to begin developing a statewide GIS database. The agreement specified that DEM would design and prioritize applications. NRS would begin development of a statewide spatial database and carry out GIS analyses.

Following the recommendations offered in the feasibility study, the software product ARC/INFO was purchased and installed on a Prime 9955 minicomputer at the University of Rhode Island Academic Computer Center. The Environmental Data Center (EDC) was created and this was the focal point of GIS data entry, analysis, and map production. Peripheral computer hardware at the EDC consisted of two digitizing tablets, two color graphics terminals, a monochrome graphics terminal, an ink-jet printer, two microcomputers, and a E-size pen plotter. These devices communicated to the Prime minicomputer through an 8-port multiplexor on a dedicated 9600 baud telephone

line.

EDC staffing consisted of a full-time Project Director, a full-time Operations Manager, two half-time graduate students, and varying numbers of undergraduate work-study students. The Project Director was responsible for all aspects of the project, the Operations Manager coordinated data entry and data processing activities, and the graduate and undergraduate students entered and processed GIS data. DEM dedicated a staff position to GIS Project Coordination. This individual established DEM data entry and analysis priorities and relayed data processing tasks to the Director of the EDC. Two departments at DEM played a prominent role in GIS activities and these were the Division of Groundwater Resources and the Narragansett Bay Project.

2.4 RIGIS Goals

The ultimate goal of the RIGIS Project is to make GIS data processing an integral part of the effort to protect and manage the State's natural resources. The short-term RIGIS objectives were to begin development of statewide coverage for fundamental data layers (hydrography, borders, aquifers, etc.), to demonstrate the utility of GIS processing for natural resource managers, and to incorporate GIS methods into the academic (teaching, research, and service) arena.

3. LESSONS LEARNED FROM THE FIRST TWO YEARS OF RIGIS

We have learned a great deal during the first two years of RIGIS. We have found that some of our initial managerial and technical decisions were correct. We also made mistakes. When the mistakes were recognized we have attempted to correct them. We will review the major issues facing a new GIS Program in terms of organizational challenges and technical demands.

3.1 Organizational Issues

The expenses of establishing and maintaining a GIS program are not trivial and we assume that any program that is considering to engage in GIS data processing is making a long-term commitment to the project. It is imperative that the initial project organizational scheme be flexible. All project players learn a great deal in the

first few years and as administrative and technical staff mature in their awareness of GIS methods, organizational plans might need modification. During the first two years of the RIGIS Project, the EDC/DEM relationship was one based on maximum responsiveness. Priority tasks frequently changed and this would sometimes require that an ongoing project be temporarily postponed so staff and equipment resources could be dedicated to a new application. This is to be expected and new GIS sites should be certain that their organizational schemes be dynamic. In the future, we hope to have staff and equipment that can be mobilized rapidly for rush or emergency applications without negatively impacting on-going projects (see discussion of SWAT processing in August and Wright, 1987).

GIS methods were a new concept for DEM program managers. Forkey et al. (1986) provide a thorough review of incorporating GIS into the Rhode Island Groundwater Management Program. They found that a number of application design issues required a great deal of careful deliberation. These include assessing the suitability of data for GIS entry, evaluating the accuracy of existing data relative to the accuracy required for various analyses and modelling efforts, determining who will be responsible for QA/QC, and establishing project timetables when GIS processing times are unknown.

Many of the uncertainties that face program managers are due to an incomplete appreciation for the GIS Concept. Technical staff who use GIS software on a daily basis are clearly aware of the powerful analytical procedures that GIS makes possible (e.g. overlays, buffering, Boolean query of the database, etc.). However, program managers who do not have a high level of technical expertise are sometimes unaware of easily executed GIS procedures and what tasks can be slow and laborious. If program managers are to incorporate GIS products into their operations, it is imperative that they appreciate what can and cannot be done. It is not essential that they know how to use the software and hardware, but it is essential that they are familiar with what the GIS is capable of. This soon became very apparent to RIGIS technical and administrative staff. To improve communication between management and data analysts, the EDC gave a semester-long workshop to DEM managers on using GIS tools. The course was held two evenings a week (three hours each evening); one meeting of which was dedicated to new concepts and the second night was dedicated to application of the concepts learned the previous meeting. Emphasis was placed on using GIS data layers, not creating them. The participants of the workshop included representatives from DEM programs in groundwater management, environmental planning, wetland protection, and the Narragansett Bay

Project. The most important result of the training course was the heightened awareness of the GIS Concept. The tangible manifestation of this was more creative applications design, realistic project timetables, and a mutual understanding of what DEM needed and what the GIS offered.

Awareness of GIS concepts by high level management is critically important. It is frequently the upper management that is responsible for obtaining the funds necessary to implement a GIS. The same individuals are frequently called upon to justify the expense. Database design and development is a slow process. For example, we estimate that it takes approximately 100 person-hours to automate one 7.5 minute quadrangle of soils data (approximately 2,300 polygons). A dilemma arises when funding agencies wish to see products from their GIS investment before major databases are developed. RIGIS placed a high priority on demonstration applications early in the project. The data for these demonstrations were not of extreme cartographic accuracy but reflected the analytical potential of the system. With careful planning, demonstration projects can be developed rapidly with minimal impact on technical resources. The public relations and project justification returns on a well designed demonstration can be substantial. High-level administrators must appreciate the time involved in database development. In the meantime, "quick and dirty" data layers that are "for illustrative use only" can be used effectively for demonstrations.

GIS managers must address issues of data security. Oftentimes, data layers contain confidential information or data that require field verification (e.g. pollution sites, landuse). Depending on the architecture of the GIS system, issues of data security may, or may not be relevant. Nevertheless, we have found it to be a significant issue for some applications and new sites should address this component of project organization.

RIGIS has discovered that GIS products can be especially attractive to municipalities or special interest groups. We have found that town planners and conservation commissions are anxious to see the system demonstrated. Given that state funds are supporting the project, it is important to illustrate to the tax payers how the state is going about the business of managing the environment. Demonstrations of the power and accuracy of GIS can be a very effective public relations tool. When an audience realizes what the system can do, their first response is usually to ask how they go

about getting products and analyses conducted for their own special interests. GIS Project managers must recognize from the onset that demand on the system can grow rapidly. GIS Project design might include, from the beginning, a way to serve the interests of groups outside of the start-up agencies. Forkey et al. (1986) describe this aspect of GIS organization in their discussion of the "Free Rider, Bandwagon, and Candy Store Syndromes."

The funds to support RIGIS are obtained from the budgets of different divisions at DEM and federal grants to DEM. We are now trying to establish a funding base that is stable and does not cut into the budgets of departments within DEM. How this will be accomplished is not clear at this moment and we are examining a number of possibilities. We are working toward developing a truly multidisciplinary statewide database. This will involve active participation by agencies other than DEM. Coordination within one agency can be a major task. Coordination among numerous state agencies will be even more challenging. Whatever the final budgetary recipe might be, the system has to be accessible to users, the data must be accurate and well documented, and there must be continuity in database development and application planning.

3.2 Technical Issues

The technical staff of a GIS project must work in concert with program managers. It is imperative that lines of communication remain open and clear between the data processing staff and the application designers. It is important for technical staff to know why they are doing what they are doing. Conversely, it is valuable for administrators to be aware of how tasks are technically accomplished. There is a big risk of the "black box" element to creep into GIS programs. Managers may assume (and dangerously so) that what the system produces is correct. Technicians can easily be lured into a false sense of critical complacency by assuming that if the data came from X, they must be correct. Misunderstandings between project designers and project GIS staff can result in erroneous products. Communication between these groups will help minimize this problem.

Perhaps the most important early decision GIS project players must make is how to manage the database. If data are not readily retrievable, they might not be used. The database management system must be able to grow with the database. There is no set recipe for

database design; each project will have unique demands. There are, however, fundamental questions that should be asked. These include how should data layers be stored (by quadrangle, town, county, state, etc.), what cartographic coordinates should be used (latitude/longitude, state plane system, Universal Transverse Mercator coordinates), who will compile the data, who will maintain the data, who can use the data, how accurate do the data need to be, and what map scale should be used in database development? We can not overemphasize the importance of these issues. A hastily made decision early in a project might require considerable time to resolve at a later point.

Issues of quality assurance and quality control (QA/QC) must be addressed early in a GIS project. QA/QC itself has many dimensions. For example, in Rhode Island, application managers resolve the initial questions of the accuracy of existing map data. Once map manuscripts are provided to the EDC, data entry staff must maintain strict QA/QC as data are automated. The EDC strives to maintain line accuracy to within 0.01 inch of the original manuscript. This can be done objectively (assuming high quality drafting). If a data entry operator can see white between the ink line (approximately 0.01 inch wide) of a proof plot and the line drafted on the original manuscript, the digitized line is at least 0.01 inch off. In this case, the arc segment is deleted and re-digitized. Matters of line accuracy must be viewed pragmatically. If the data on a particular map manuscript are only rough approximations of reality, it may not be practical to be overly concerned with 0.01 inch line accuracy. There is a delicate balance between emphasis on accuracy and the need to build the database. It is all too easy to belabor issues of accuracy to the point where data are not entered in a prompt fashion. We must continually remind users that if deviations in line accuracy 0.01 inch from the original map manuscript are significant to an application, the user should probably not be working with data at that scale.

Issues of data documentation and data maintenance are significant. RIGIS is still experimenting with different methods of communicating data layer documentation. We have an online data dictionary that reports the source of the data, the contact agency, when the data were entered, and how the data are coded. We also use paper documentation to communicate the same information. Issues of documentation would best be resolved early in a project before the database becomes especially large. What might be the best format depends on the needs of each site and sometimes, each application. Database maintenance is another issue that has no simple answer. A

landuse dataset that is 10 years old has much less value than a current landuse coverage. An incomplete dataset on point sources of pollution could be a source of major problems. If a user is not aware that data are not current (faulty data documentation), highly erroneous conclusions might be drawn from an analysis. Maintaining dynamic datasets is a major task and one that should be examined before any attempt is made to enter the data into the GIS database.

The RIGIS project may be somewhat different from other GIS installations in that graduate and undergraduate students comprise our data entry staff. Training students in contemporary analytical methods (e.g. GIS data processing) is consistent with the teaching mission of the University. We have found that students are capable of excellent quality work and they are often eager to learn the system, especially when they anticipate using GIS tools in their thesis research projects. Indeed, every graduate student who has worked at the EDC has incorporated, to some extent, GIS products into their theses. Our graduate and undergraduate students typically major in Natural Resources Science, Zoology, Geography, and Geology. Project administrators have to maintain a rather flexible work schedule when using student workers. It is impossible to hold students to a rigid schedule during midterm or final exams. We have a constant need to train new student staff. The best we can expect is two to three years commitment to the GIS project and this results in a fair amount of turnover.

A number of important technical resource needs for multi-user GIS sites, like RIGIS, has been reviewed by August and Wright (1987). They note that it is important to recognize the need for experimentation with software/hardware by technical staff. Time invested in experimenting with the system may result in better, faster, more accurate ways to process or image data. They also describe how maintaining a GIS database consists of central and peripheral tasks. Central tasks are those which contribute directly to database development. Peripheral tasks are those that are critically important but do not relate directly to data entry or analysis. Examples of peripheral tasks are troubleshooting hardware and software problems, training, demonstrations, and experimentation. Peripheral tasks can not be neglected in designing a GIS program.

It is becoming apparent that a number of specific data layers keep emerging in GIS analyses of natural resource issues. Landuse/landcover, soils, and topographic data are fundamental to

many projects. A current challenge that RIGIS presently faces is obtaining the resources to automate these data. The 100 hours it takes to manually digitize a one-quad area of soils data (scale 1:15,840) can be reduced 70 % by automatically scanning line segments. Scanning costs range from $500-$1,000/quad. Rhode Island is a small state and encompasses only 38 quads. However, funds to initiate a statewide soils digitizing project are difficult to obtain. Landuse/landcover and topographic data are also complex datasets that are expensive to develop but they are critically important. Landuse data are especially problematical because of the dynamic changes that occur in the Rhode Island landscape over a short period of time. A 10 year old landuse dataset is a valuable historical resource but in areas where development is proceeding rapidly, it does not indicate the current landscape mosaic. Satellite imagery may be a valuable source of landcover data but applications that focus on a small geographic area frequently require much better resolution than remote sensing can provide. The issue of complex datasets is not unique to RIGIS. Discussions with colleagues in other statewide GIS Centers face the same problems. Hopefully, federal agencies like USGS and SCS will continue and expand their important programs in automating soils, landuse/landcover, and topographic data.

The technical staff at RIGIS have learned a great deal from similar programs in other states. ARC/INFO sites in the northeast United States have formed the Northeastern ARC/INFO Users group and meet twice annually. These meetings have been an extremely valuable forum for exchanging processing tips and software/hardware development news. RIGIS staff will frequently call a colleague in a neighboring state to resolve a problem rather than contacting the hardware or software vendor. In short, communication among GIS sites should be encouraged.

4. SUMMARY

The Rhode Island Geographic Information System Project has been operational for two years. During this period we have begun development of statewide data coverage for many important data categories. GIS data processing has now become an integral component in a number of important state programs. RIGIS has been able to provide municipalities with GIS products that have influenced important decisions on land management. The GIS has catalyzed interagency coordination and cooperation in database design, data transfer, and project analyses. At the University, graduate students and faculty are incorporating GIS methods into their teaching and

research programs. At minimum it is clear that GIS can play a significant role in State Government and academic institutions. If sufficient funding can be found to complete the statewide database and to connect environmental programs and their staffs into the database on a continuous basis, then GIS can become an essential tool through which the State's environment can be understood and managed for the first time in a way which can avert, rather than react to, environmental threats.

5. ACKNOWLEDGEMENTS

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SLICED VEGETATION MAPS

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ABSTRACT

Existing vegetation maps, utilizing principally the communication paradigm, mask much of the data from which they are derived. Modern spatial information systems provide a means of preserving the vegetative data integrity, while displaying plant distributions in a form which is recognizable to the casual map user. Furthermore, using the old concept of "sliced maps," within an automated geographic information system, the data are transformed to a usable analytical framework from which natural resources information can be extracted for subsequent decision making. The methodology involves creation of a data base which includes separate vegetative characteristics, such as species number, number of saplings and seedlings and diameter at breast height, together with soils, topographic and cultural data. From this unique data base design numerous displays of vegetation data, either separately or in conjunction with the non-vegetative data, provide extremely flexible analytical capabilities previously lacking in traditional vegetation mapping. Three examples illustrate progressively complex analytical designs involving the sliced vegetation data base to create individual map presentations which enumerate selected features of the study area. Many modifications of these three methods are possible as well as a wide range of alternative analyses when such a data base design is utilized. In order to prohibit rapid expansion of the data base, however, it is suggested that only those vegetative parameters which are of immediate use be included in any analysis. Further research is needed to determine subsequent or alternative data for inclusion in vegetative data base design, and to determine the behavior of biological surfaces prior to factor interpolation.

1. INTRODUCTION

The earliest vegetation maps, those generally appearing in the fifteenth century, displayed vegetation in a form more decorative than communicative (1). During the sixteenth century, with the recognition of the significance of vegetation maps for military, resources and other uses, these decorative displays were replaced by more accurate depictions of the aerial extent and location of vegetation (1). These

are considered to be the forerunners of today's traditional vegetation maps.

Traditional vegetation mapping, however, is based largely on the communication paradigm, a model designed to display the cartographic product to illustrate a selected spatial pattern. This time honored approach produced in the past, and still produces today, many of the most beautiful of maps. Unfortunately, in order to portray vegetation in its natural diversity, within the framework of a single piece of paper, enormous amounts of data are necessarily reduced to categories which often satisfy only specific uses. It is therefore, frequently necessary to produce a number of types of vegetation maps based on the uses for which they are intended (2).

This limited utility is magnified when analytical operations are to be applied to the cartographic product for natural resources decision making. Frequently, the vegetative information is so aggregated as to be of only moderate utility in such analytical work. In traditional cartographic applications what would be necessary, then would be to create a separate map for each needed application, or to rely on the existing display with only limited results.

2. THEORETICAL CONSIDERATIONS

An alternative solution is suggested by Khan (3) to introduce a series of cartographic overlays, or "flying sheets" to the cartographic process. Kahn's model, designed for use by the Indian Forest Service, involves a systematic overlay of five vegetative slices, each designed to represent particular botanical features. He proposes a base map (A) which is a topographic map, with flying sheets B and C presenting soil and ground-cover synusias. Sheet D shows the middle synusia and flying sheet E, the uppermost synusia. True to the communication paradigm, Khan also proposes a systematic use of colors and symbols, shades and hues assigned to each of the five maps.

This suggested model indicates that, in some ways, Khan was far ahead of his time by essentially proposing manual GIS applications for natural resources decision-making. Certainly he was limited by the manual methods available at the time, but equally he adhered too closely to the conventional cartographic methodology of his day. Moreover, and as Kuchler (1) points out, there are some inherent problems with the choice of slices proposed in this methodology, however, I do not believe that they are the problems which Kuchler identified.

In his observation of Khan's proposal Kuchler states,

> Khan observes repeatedly and quite correctly that there is a real need for maps showing the phytocenoses because they form the best foundation for sound silviculture and forest management. But his sliced maps seem to cut right through the phytocenoses and some way must be found to overcome this difficulty. Perhaps topography and soils can be combined on one of the flying sheets B or C, leaving the base map A for the phytocenoses.

I believe that under the restrictions of the communication paradigm and of the manual methodologies of the day, this may have appeared to be true. However Kuchler's recommendation to combine, for example, soils and topography as one of the flying sheets, seems to be in conflict with Hartshorne's (4) statement that, "...in studying the areal variation of plant life, we cannot think in terms of its relation to a separately existing integration of rainfall, temperature, inorganic soil material, slope and drainage..." This suggests an alternative methodology which would allow the combination of selected environmental factors within the construct of a given analysis. If, as is proposed in this research, the phytocenoses were instead further subdivided, ie. "sliced" the ordination and classification of the vegetation, and the selection of appropriate factors could become part of the decision process and would allow greater flexibility in the final cartographic display as well.

The methodology is based on a floristic, rather than a physiognomic approach as originally proposed by Kuchler (5) and expanded on by Wagner (6). Although Kuchler (1) would consider this approach to be categorized as "specialized vegetation maps," that consideration would be based largely on the communication paradigm. It would follow, therefore, that he would expect the map to be presented on a single sheet, and its utility limited to a single purpose. Rather, the design is quite utilitarian, its intended use limited only by appropriate analytical combination of individual, species specific, map sheets. Each map sheet contains only a single variable relevant to each species, further allowing the data to be manipulated at will. Within traditional, hand-drawn cartography, such a methodology would have been precluded.

Current spatial information system technology allows many of the processes called for in this "sliced vegetation maps" methodology to be performed in a rapid and painless manner. A demonstration of some of the more obvious analyses which can be performed with even a simple, raster based GIS, is used to enumerate the immediate applications, to suggest others and to specify some needed modifications to existing GIS technology for the implementation of

still further natural resource applications of the sliced vegetation maps methodology.

3. METHODS

3.1 Study Area

Two basic requirements dictate the selection of an appropriate study area to demonstrate the sliced vegetation maps approach; data availability and vegetative variation. As such, the Fowler Woods State Nature Preserve, located in Butler Township, Northeast Richland County, Ohio is selected for this study (Fig. 1). The natural setting of this 133.5 acre tract has allowed as many as 212 species of firns and herbs and 58 species of woody plants to comprise Beech-Maple Forest, Swamp Forest, Successional Forest, and Open Field categories (7, Fig. 1). Within the study area, detailed vegetation sampling and surveying have

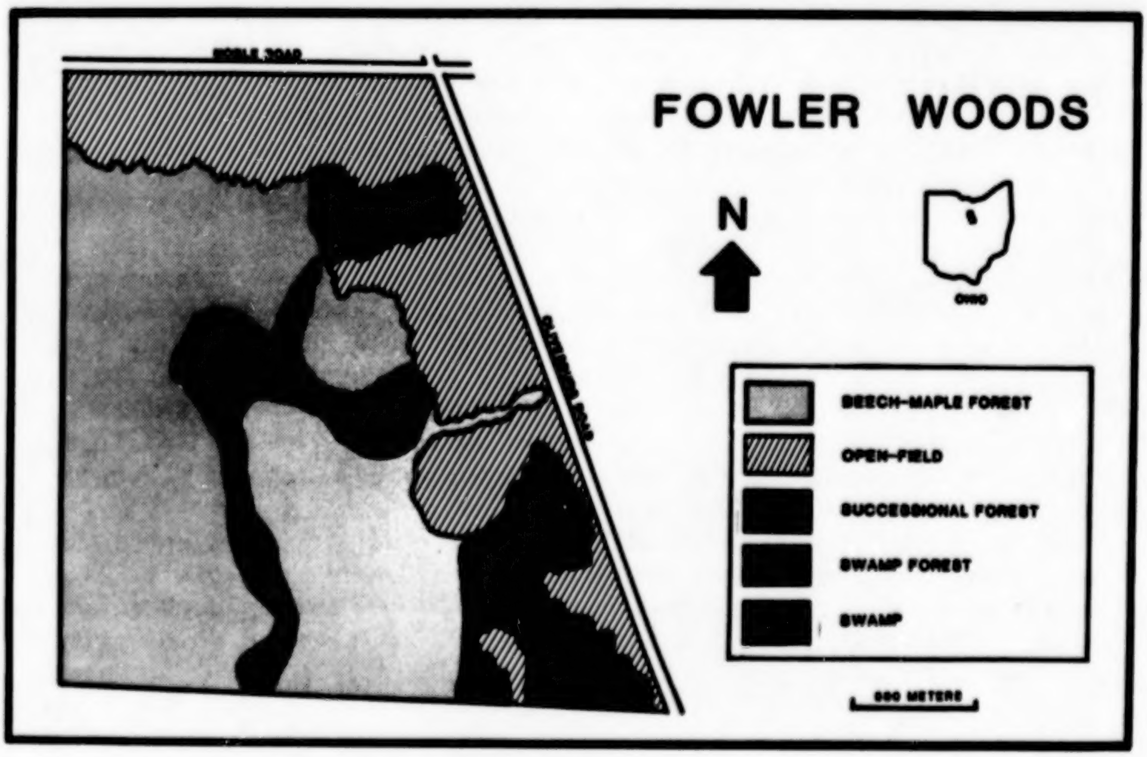

Figure 1. Study Area

been performed along randomly selected, permanently placed locations within the forested portions of the preserve (8). Additional

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resources available concerning the Fowler Woods area, including a completed soil survey, topographic map, historical aerial photography and aerial photography concurrant with the vegetation survey make the study area ideal for this demonstration and future research applications.

3.2 Data Base

The pMAP program, a raster based geographic information system running on IBM PC's and compatibles, is used to store, analyze and output data corresponding only to forest vegetation. As close as is reasonably possible, 10 X 10 meter cells are aligned to correspond to the existing 10 X 10 meter quadrats used for the original data collection for trees. Data from the 5 X 5 meter subquadrats used for saplings and seedlings are multiplied by a factor of 4 to simulate sampling on the larger 10 meter plots. It should be noted here, that, although it is recommended that the pixel sizes be smaller than this, such a small pixel size would enlarge the data base unnecessarily for the current illustration.

Each data layer corresponds to a particular aspect of each tree species. For example, maple distribution is mapped by assigning the total number of such trees to the given pixel in which they fall. Also, the average diameter at breast height (d.b.h.) of maple is recorded as a separate map data base layer. Similarly, available aspect separates of soils, topography, hydrology and cultural data are recorded as unique layers.

An 80 row, 76 column clear acetate grid overlay allows data encoding employing the different methodologies as recommended by Berry and Tomlin (9) for the different data types. Linear data, such as walking paths and roads utilize the presence/absence method, areal data such as soil survey data, and point data, such as sample plot locations are encoded by the maximum occurance method. Finally, topographic data are recorded by selecting the contour line/grid cell intersects which most closely approached the centroid of the grid cell, and are later interpolated throughout the map.

As one might expect, with 58 species of trees alone, this could produce a voluminous data base far beyond the available capacity of the pMAP program's 100 map maximum. In order to demonstrate the utility of the sliced vegetation maps concepts, however, it is not necessary to include all such data. Therefore, a small subset of the

vegetative data is created, representing only those species occuring frequently in the Fowler Woods area.

Since the vegetative data are samples of the map area, interpolation is used to estimate the data as they might occur across Fowler Woods. There are limitations to the use of such techniques through the pMAP package, and many biological surfaces would be better modeled through Fourier series (10) as one example. With the limitations in mind, an iterative combination of filtering and discrete interpolation is used as a recommended combination for pMAP, especially in times of limited sampling (11). This completed, a mask of non-forested vegetation is added to the final map for esthetic reasons and the original non-interpolated maps are discarded to reserve room for maps created through analytical procedures.

4. EXAMPLES

Examples are selected from three major categories of analysis merely to indicate the adaptability of the model, rather than to illustrate all the possibilities, since such an exhaustive set of analyses is far beyond the analytical capabilities of a single researcher. The categories are designed to indicate a range of applications relevant to different resource scientists with different information needs from the same data base. The three categories include, 1. Raunkiaer's species frequency mapping, 2. species dominance mapping and 3. importance value index mapping.

4.1 Raunkiaer's Species Frequency Mapping

Frequency is concerned with the uniformity of a species as it is distributed throughout a community. Raunkiaer (12) was the first to recognize the statistical significance of occurance or absence of species in sample units. His model breaks the species into five frequency classes in 20% class intervals, and is based solely on the presence or absence of species within a given plot. This method can be given a spatial representation within the sliced vegetation maps methodology in the following manner.

```
CMD> RENUMBER (SPECIES#)MAP ASSIGNING 1 TO 1 THRU 100 FOR /
     (SPECIES)OCCURMAP
```

The output map legend percentages must be adjusted to account for areas not included in the study. A combination of species frequency, or species occurance maps can be performed by merely adding the maps together as in the following.

```
CMD> COMPUTE (SPECIES1)OCCURMAP PLUS (SPECIES2)OCCURMAP /
     PLUS... (SPECIESn)OCCURMAP FOR DIVERSITYMAP
```

Thus, creating a map indicating the co-occurance of many species in a given location (Fig. 2). This particular technique is useful for

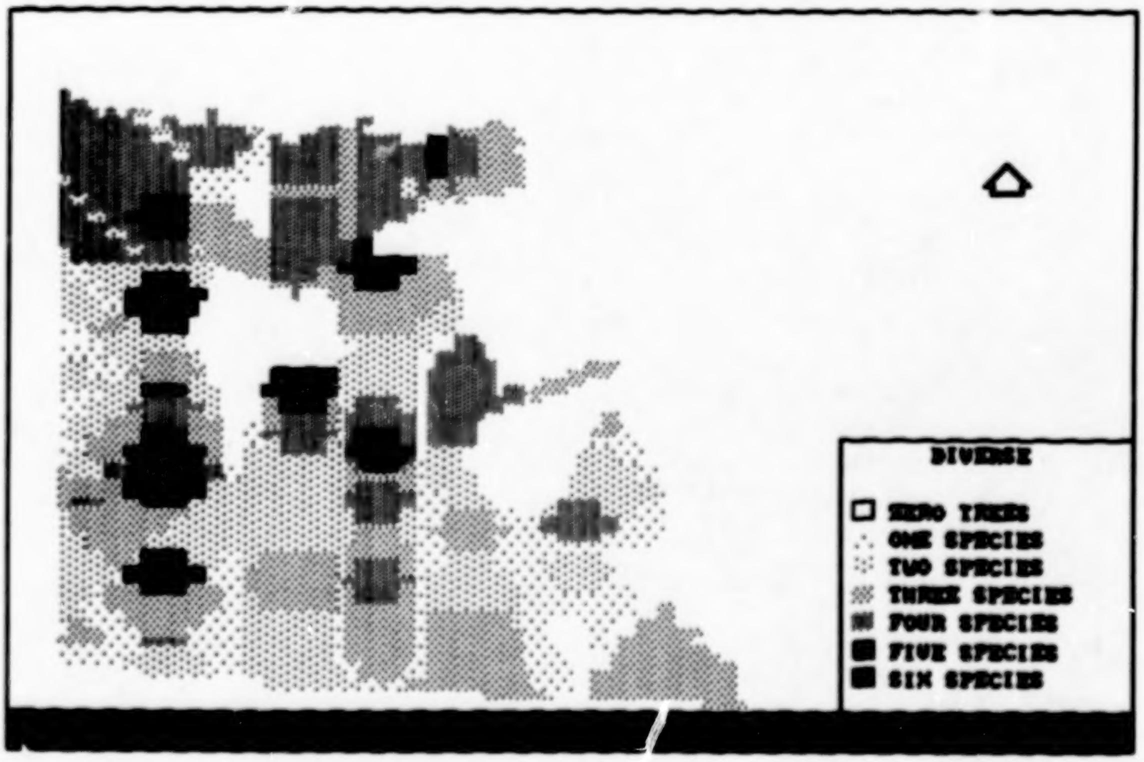

Figure 2. Species Diversity Map.

identifying those stands which are more or less pure. Study can also be applied to the relationship, for example, of diversity of species to selected soil types by combining the soilmap categories with the diversitymap in the following manner.

```
CMD> RENUMBER SOILMAP ASSIGNING 100 TO SOILTYPE# FOR
     (SOILTYPE)SOILMAP
CMD> COMPUTE DIVERSITYMAP PLUS BNBSOILMAP FOR INTERIMMAP
    CMD> COMPUTE INTERIMMAP MINUS 100 FOR INTERIMMAP2
    CMD> RENUMBER INTERIMMAP2 ASSIGNING 0 TO 1 THRU 6 FOR
             VEG(SOILTYPE)SOIL
CMD> LABEL VEGBNBSOIL
     >> 0 NO TREES
     >> 1 1 SPECIES
     ...
     >> N N SPECIES
             >> ...
```


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Thereby defining which soils support the most diverse types of vegetation. Similar techniques can also be performed for topographic slices to indicate the effects of slope angle and direction on the diversity of species.

4.2 Species Dominance Mapping

Of equal importance to species diversity is its dominance, in this case as manifested by comparative analysis of species richness (number of trees per unit area) and species basal area (as determined by d.b.h.). Since it is accepted that diversity measures based on both diameter class and species number are more indicative of species dominance the following methodology creates useful maps for the resource manager.

```
CMD> SLICE (SPECIES)DBH INTO 5 FOR (SPECIES)DBHCLASS
```

This creates five categories of diameter class for analysis of the number of trees of the given species which occur in each d.b.h. class. Such a table has been found useful by Cain (13) and can be computed and given a spatial dimension (Fig. 3) using these pMAP commands.

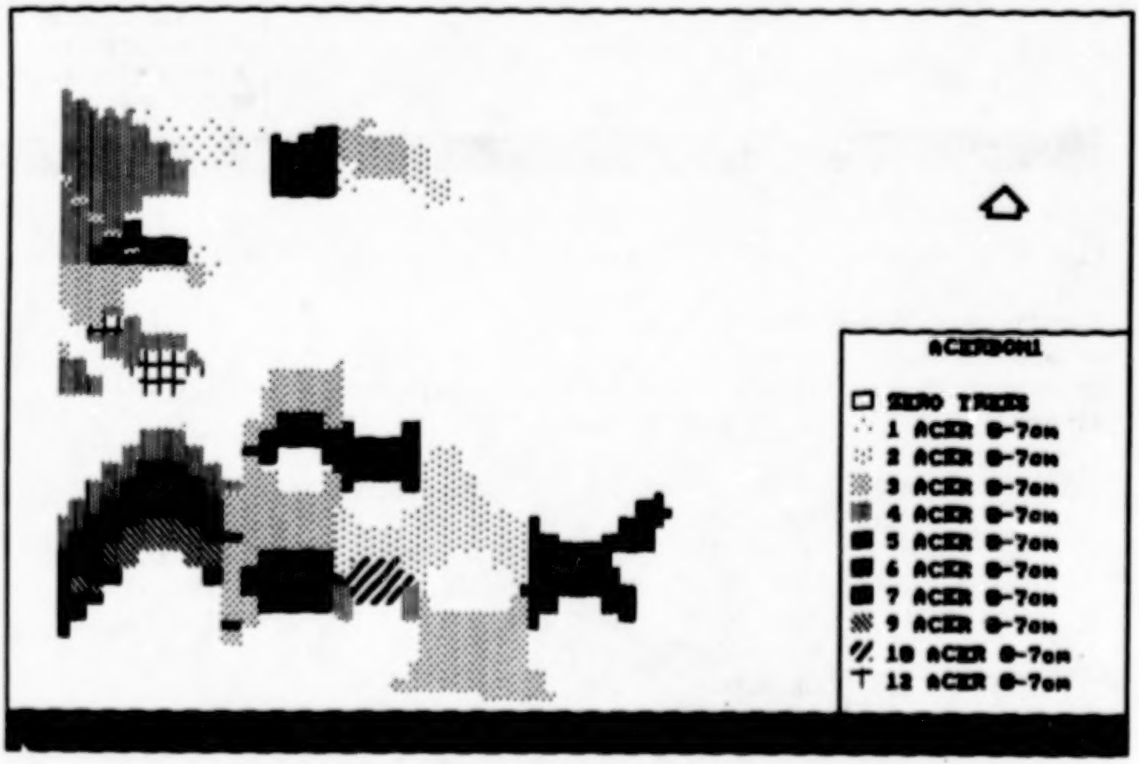

Figure 3. Species Dominance Map for Acer(sp) and d.b.h. class 1.

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```
CMD> RENUMBER (SPECIES)DBHCLASS ASSIGNING 100 TO CLASS# FOR
     INTERIM
CMD> COMPUTE SPECIES# PLUS SPECIESCLASS# FOR INTERIM
CMD> RENUMBER INTERIM ASSIGNING 0 TO 1 THRU 99 FOR INTERIM
CMD> COMPUTE INTERIM MINUS 100 FOR SPECIESDOM#
```

4.3 Importance Value Index Mapping

A natural culmination of the previous analyses involves the combination of community characteristics to enhance description. Such a description often takes the form of an importance value. The existence of a spatial distribution of spruce forest, for example, does not indicate the importance of the forest for particular uses. In many applications, a map of such an importance value would be far more effective than the traditional classification systems. The following example utilizes the sliced vegetation layers of the data base to recreate the Importance Value Index (IVI) recommended by Curtis and McIntosh (14). This method is one of many designed to determine site quality as defined by foresters and conservationists (15).

The IVI for any given species is an additive combination of relative density (the proportion of a species density to that of the whole) with relative dominance (proportion of the basal area of a species to the whole stand) and relative frequency (proportion of species occurances to that of the whole stand). In order to calculate each of these relative measures, the following must first be enumerated from within the data base: 1. Density of each cell (number of individuals per cell), 2. Dominance of each cell (computed from average basal area in each cell), and 3. Frequency of species (number of cells in which a species is represented. Since the current data base does not contain average basal area, these must first be calculated for each map from the dbh in order to have the essential elements called for in enumeration 2. Allowance is also made for integer mathematics by adding one to the data base before average basal area is calculated, and is later subtracted. The following procedural formulae, stated in pMAP query format, are used to compute the IVI for any or all species in the data base.

```
CMD> COMPUTE (SPECIES)DBH PLUS ONE DIVIDEDBY 2 SQUARED /
     TIMES 2.14 FOR (SPECIES)AREA

CMD> COMPUTE (SPECIES)AREA1 PLUS (SPECIES)AREA2 PLUS ... /
     (SPECIES)AREAN FOR TOTALAREA

CMD> COMPUTE SPECIESAREA TIMES 100 DIVIDEDBY TOTALAREA FOR
     (SPECIES)DOMINANCE
```

CMD> COMPUTE (SPECIES1)# PLUS (SPECIES2)# PLUS (SPECIESN)# /
FOR SPECIESTOTAL

CMD> COMPUTE (SPECIES)# TIMES 100 DIVIDEDBY SPECIESTOTAL FOR
(SPECIES)DENSITY

Where (SPECIES) is the genus or species in question and (species frequency) is determined using the DISPLAY command and is derived from the legend. The final formula, then is ...

CMD> COMPUTE (SPECIES)DENSITY PLUS (SPECIES)DOMINANCE /
PLUS (species frequency) FOR (SPECIES)IVI

Which, when applied to acer, for example, will yield a spatial coverage of the Importance Value Index for the various species of maple (Fig. 4). Since this final map will involve a great many values over 100, it will be necessary to use the SLICE command to display the final values in a meaningful fashion. These IVI maps can be created for each of the species or genera involved, or a composite IVI value can also be created

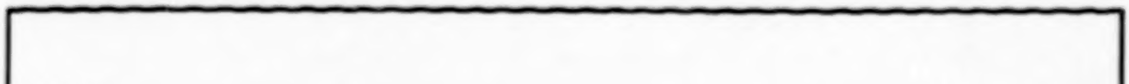

Figure 4. Importance Value Index Map for Acer(sp).

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for all species. Such maps provide an important tool to the resource planner in selecting areas for preservation, research or special care and consideration.

5. CONCLUSION

It has been demonstrated that a geographic information system data base design, centered on the enumeration of individual vegetative data separates, or sliced vegetation maps, is potentially very valuable to a multitude of users. The method allows the greatest flexibility in both analysis and cartographic display capabilities. It further enumerates methods of capturing and storing existing field collected vegetative data in a manner suggested by Thalen (16) for future research once new modeling methodlogies are developed. Such data are often not used beyond a single study due to the difficulty of obtaining them. It is hoped that this research will suggest even more exploration of the potential of sliced vegetation maps data bases. It should further suggest the applications of alternative or correlative data to additional modeling such as the hydrological correlations used by Everts and others (17), or a microclimatological homoclinal analysis modified from Booth, et al. (18). These models must be attempted to both ascertain the utility of GIS technology to such problems and to suggest needed modifications to the technology.

6. ACKNOWLEDGEMENTS

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COMPUTER MAPPING FOR COAL GRADE EVALUATION

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ABSTRACT

The West Virginia Geological and Economic Survey has developed a computer mapping technique to appraise the occurrence of various grades of coal within the State. Using a coal-quality database consisting of information on moisture, volatile matter, ash, Btu, and other chemical and physical parameters, the Survey is able to rapidly construct maps to present this coal-quality information to the public.

The computer program provides a flexible approach to tailor quality-maps for seams to the needs of the user. To control the degree of smoothing, linear geostatistics (kriging) estimates expected mean values on a regular grid. Most datasets for mapping display non-normal distributions and include outliers; robust methods are used for computing semivariograms and estimating central tendency. Nonparametric geostatistics yield robust estimates when the observed frequency distribution of a variable includes a long tail. The method works by reducing a dataset to indicator variables corresponding to a number of thresholds and constructs a cumulative frequency distribution on the grid. The user can map robust means, medians, probability of exceeding a given value, and expected value at some percentile of the frequency distribution. The result is a set of maps showing risk-qualified estimates.

This mapping procedure allows for potential customers of West Virginia coal to receive unbiased and accurate-as-possible mapped information. This appraisal, in turn, may shorten the time between deciding to acquire coal and locating a coal supply.

1. INTRODUCTION

The West Virginia Geological and Economic Survey provides information to coal users and producers. Typical cases include requests to know where within West Virginia coal meets certain grades. (Grade is defined as that unique set of physical and chemical coal-quality characteristics which a user or a mine-operator desires in the "coal" product.) The "right" grade of coal varies with the application. A coking-quality coal request may have specifications of sulfur content, 1% or less, ash content, 5 to 10%, a volatile matter, 25 to 35%, and a free swelling index (FSI) of 6 to 9. On the other hand, a utility using coal for steam production will be more interested in sulfur content, Btu (heating value), and the amount of SO_x per million Btu.

West Virginia contains coal of a variety of grades. The West Virginia Geological and Economic Survey maintains an extensive coal-quality database on the grades of coal. As an unbiased source of data, our experience in the variation of coal quality provides a mine-planner or a coal buyer invaluable assistance. Using our computer, we are able to locate geographically the probable target areas where the desired grade of coal may be found—saving time and money in the search for a coal resource. These cases share a common thread. The information was best provided in the form of maps. Whereas

hand contouring was used in the past, all products are generated on a computer to control smoothing of raw data, apply objective contouring algorithms, and to save time.

Contouring has switched from *ad hoc* hand contouring and machine methods such as inverse distance squared, to the calculation of kriged estimates on a grid. Kriging has a number of advantages. In modeling spatial covariance in a set of data, the user must look at observed values at each point in the context of surrounding points, and can spot unusual values arising through error or geologic processes. Developing a different covariance model for each data set means that the geologist applies an appropriate degree of smoothing. Finally, kriging allows for clusters of sample points, directional anisotropies, and varying distances between sample points and locations where estimates are to be calculated.

Estimates from conventional, linear kriging are equivalent to local averages when data are uncorrelated spatially. Although useful in resource assessment and comparative studies, maps of expected means suffer two drawbacks: they do not indicate local variability, and linear estimates are sensitive to non-normality and outliers. The kriging variance may be used to map local variability, but only under rigorous assumptions of normality, invoking the second problem.

Given local measures of central tendency and variability, one can estimate the probability that an observed value might exceed a threshold or cutoff, and can compute a histogram at each site in an area. Nonparametric kriging (1) yields information needed in risk assessment, is easy to use once one has a basic understanding of linear kriging, requires no transformation to normality, and is robust to outliers.

2. DESCRIPTION OF METHOD

Nonparametric estimation needs one simple transformation. Given a value of a regionalized variable $z(x)$ observed at location x, and a cutoff z_c, transform $z(x)$ to an indicator variable $i(x, z_c)$, such that:

$$i(x; z_c) = 1 \text{ if } z(x) < z_c$$
$$= 0 \text{ if } z(x) \geqslant z_c$$

Continuous data such as sulfur are converted to an indicator variable having values of 0 and 1 depending upon whether the value $z(x)$ is greater or less than a cutoff value. This process is repeated C times corresponding to C cutoffs z_c. The proportion of area below a cutoff can be estimated from n observed values of $z(x)$ if the samples are spatially uncorrelated:

$$P^*(A; z_c) = {}^1/_n \sum_{k=1}^{n} i(x_k; z_c)$$

In the presence of spatial autocorrelation, one should resort to a linear estimator:

$$P^*(A; z_c) = \sum_{k=1}^{n} \lambda_k(z_c)\, i(x_k; z_c) - [1 - \sum_{k=1}^{n} \lambda_k(z_c)]\, F^*(z_c).$$

where $F^*(z_c)$ is an estimate of the expected frequency of exceeding cutoff z_c, and the n weights, $\lambda_k(z_c)$ are calculated from a system of n kriging equations:

$$\sum_{m=1}^{n} \lambda_m(z_c)\, \rho_I(x_m - x_k; z) = \bar{\rho}_I(x_k; A; z_c) \quad \text{for } k = 1, n.$$

The values $\bar{\rho}_I(x_m = x_k; z)$ are indicator correlogram values for the distance $x_m - x_k$ at cutoff z_c, and $\rho_I(x_k; A; z_c)$ are average indicator correlogram values between location x_k and the area to be estimated, A. The indicator correlogram is computed from:

$$\rho_I(h; z_c) = 1 - \lambda_I(h; z_c)/\mathrm{VAR}\, i(x; z_c),$$

where $\gamma_I(h; z_c)$ is the semivariogram value at distance h for the indicator variable created for cutoff z_c, and VAR is the variance of this indicator variable, calculated from:

$$\mathrm{VAR}\, I(x; z_c) = F^*(z_c) - F^*(z_c)^2$$

To carry out nonparametric kriging, the user selects C cutoffs; transforms raw data to C indicator variables; computes, graphs and models a semivariogram for each indicator variable; and solves C sets of equations for each node on a regular grid covering the area to be mapped. The number of cutoffs and values depend upon the user's goals. Mapping the probability of exceeding a threshold requires only one cutoff, whereas the calculation of local frequency distributions could call for ten cutoffs or more.

3. EXAMPLE

Total sulfur is part of many service requests and demonstrates the procedure. Percentages were available for 189 samples of the Pittsburgh coal in West Virginia. A histogram shows that the data do not follow a normal distribution, although no tail is present at the upper end (fig. 1). Semivariograms were calculated for each of six cutoffs (table 1), corresponding to the 25th, 50th, 75th, and 90th percentile, and to upper and lower bounds specified in an actual request for maps from a prospective coal producer. At low cutoffs (e.g. fig. 2), semivariograms exhibit weak spatial covariance, with large nugget effect, consistent with past observations that within-mine variation of sulfur is large, but regional trends exist. The spacing of our samples permits only regional trends to be mapped. At higher cutoffs, semivariograms appear similar to that for 2.2% sulfur (fig. 3), with almost no evidence for spatial covariance over distances less than fifteen kilometers. ***Sulfur manifests varying degrees of spatial covariance at different cutoffs, a fact that would be hard to infer from a semivariogram of the raw data.*** A spherical model with nugget effect was fitted to each semivariogram.

Kriged estimates at each of the six cutoffs were calculated for grid modes spaced 0.5 kilometers apart in a 10 km by 10 km area. In addition to mapping the probability of exceeding each cutoff, one can map a robust estimate of the mean $q^*(A; 0)$:

$$q^*(A; 0) = \sum_{c=1}^{C} z'_c\, [P^*(A; z_{c-1}) - P^*(A; z_c)],$$

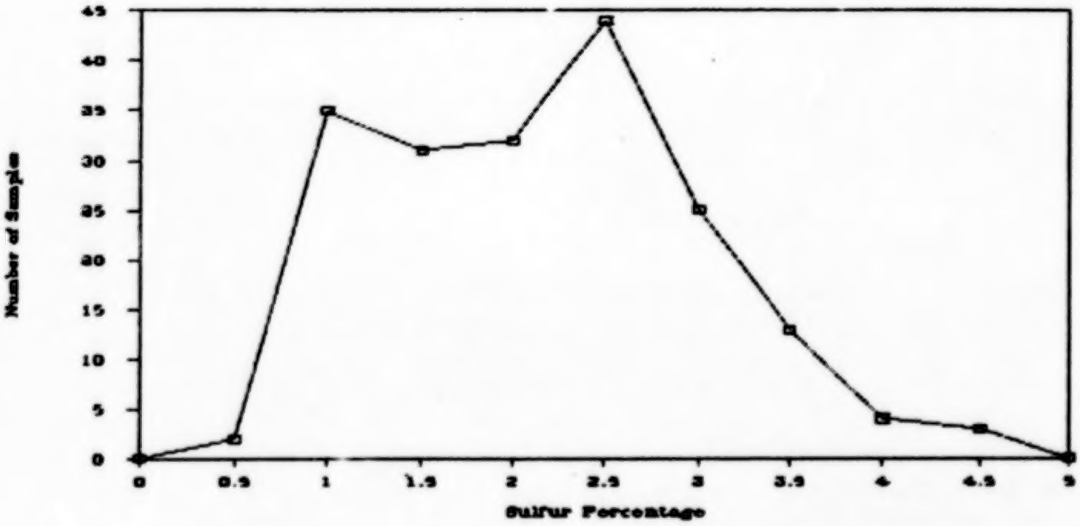

Figure 1. Histogram of sulfur percentages in 189 samples of Pittsburgh coal.

Table 1. Cutoffs, percentiles, and parameters of spherical models fitted to observed semivariograms of sulfur percentages, Pittsburgh coal.

Cutoff %	Percentile %	Nugget $\%^2$	Sill $\%^2$	Range km
1.4	25	.11	.08	15 1
1.5	29	.11	.08	10
2.2	50	.135	.10	15
2.3	59	.17	.01	10
2.7	75	.13	0	—
3.3	90	.05	0	—

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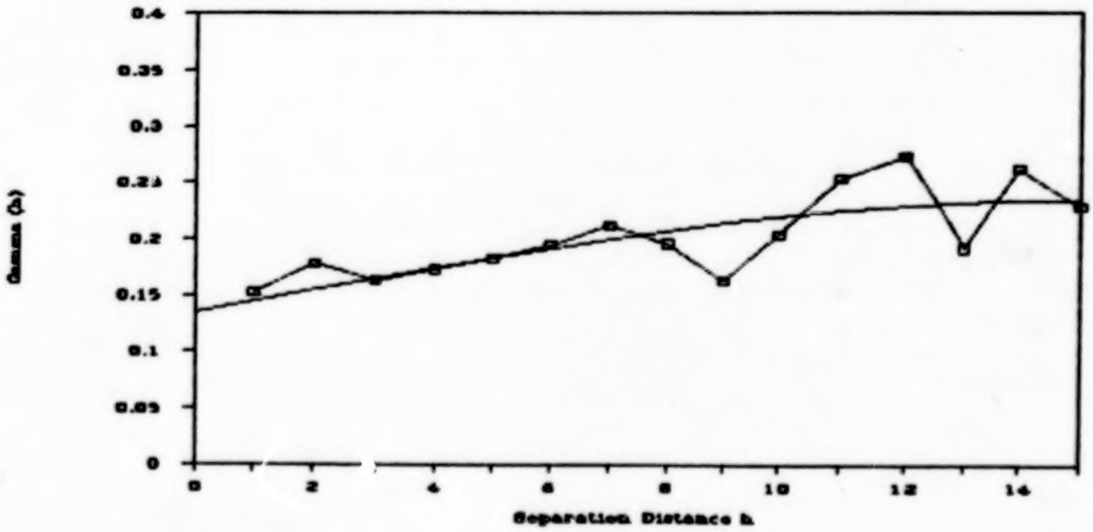

Figure 2. Semivariogram for 2.2% sulfur cutoff (squares) and model (smooth line).

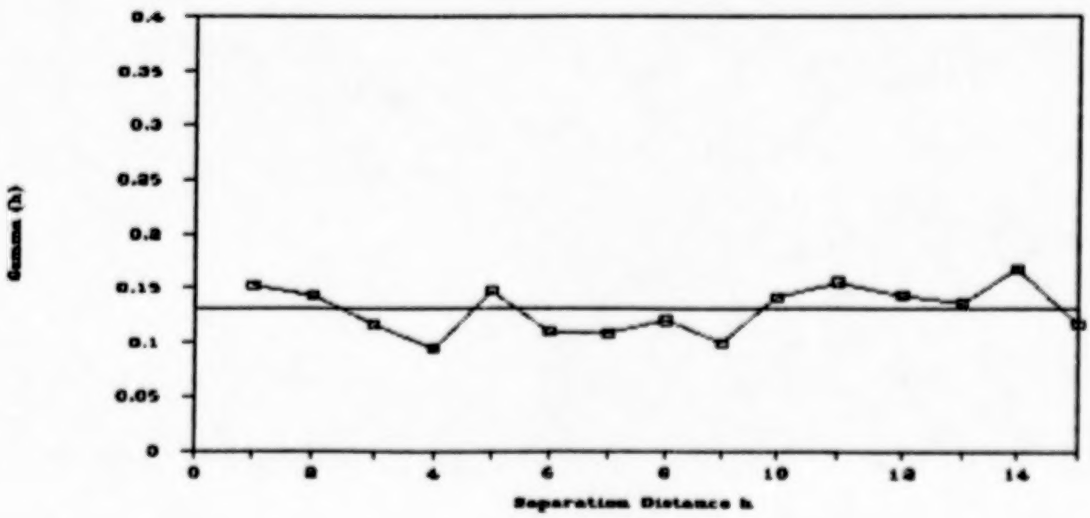

Figure 3. Semivariogram for 2.7% sulfur cutoff (squares) and model (straight line).

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where z'_c is some measure of cental tendency for the internal $[z_c, z_{c+1}]$. One possibility for z'_c is the mean of all observed values in each interval. Outliers and tails of skewed distributions may require special consideration. Even use of a simple mean should yield a more robust estimate of $q^*(A; 0)$ than conventional kriging. A map of expected sulfur percentage (fig. 4) shows that kriging has smoothed the data to a large degree; compare observed values of sulfur at control points with the contours. To eliminate edge effects, samples were included outside of the area mapped.

A map of expected median can be mapped by interpolating between $P^*(A; z_a)$ and $P^*(A; z_{a+1})$, where $P^*(A; z_a)$ is the highest value of $P^*(A; z_c)$ less than or equal to 0.5. One can interpolate to any probability level, to give confidence bands for the mean, as an example. A map of the estimated median (fig. 5) shows greater variation than the mean between high-percentage and low-percentage areas. In general, the maps show similar trends.

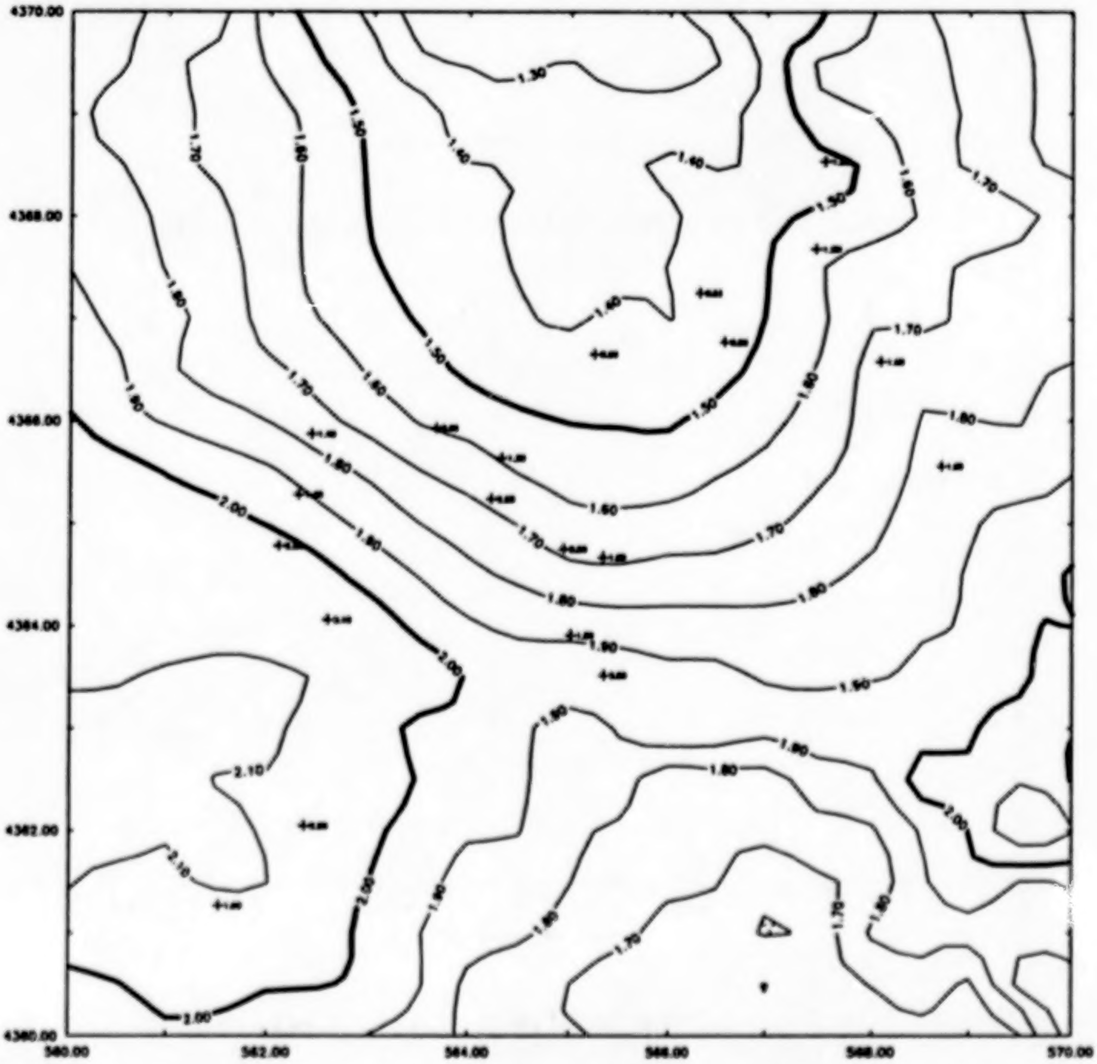

Figure 4. Contour map of expected mean sulfur in Pittsburgh coal. Sample locations are shown as crosses annotated with observed values.

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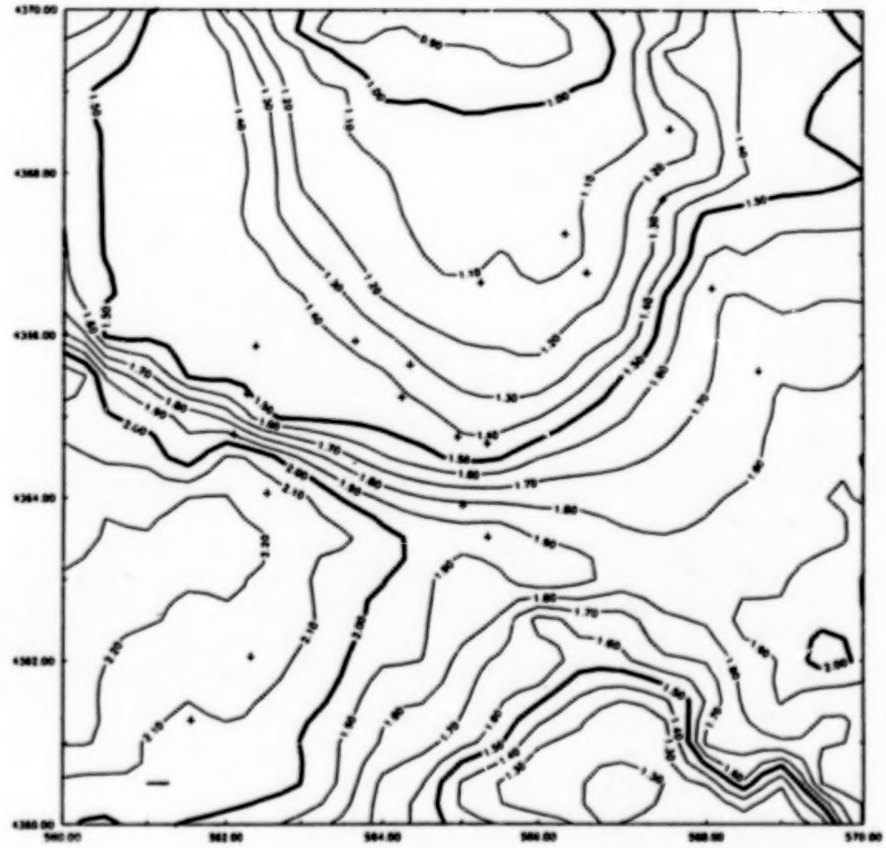

Figure 5. Contour map of expected median sulfur in Pittsburgh coal.

The probability of a sample exceeding 1.4% sulfur (fig. 6) varies in about the same pattern as the mean, unsurprising because spatial covariance was found to be most evident at low cutoffs. In contrast, the probability of exceeding 2.7% sulfur (fig. 7) is nearly constant except in one area where some very low values (0.80 - 0.90) were observed.

One request for information specified coal ranging between 1.5 and 2.3% sulfur. The nonparametric approach leads to a map showing the probability of a sample lying between these limits (fig. 8). By integrating over area and multiplying by coal thickness, an estimate of the tonnage falling within these limits could be obtained. From the map of mean sulfur content, most of the area would appear to qualify, but in fact many large areas show a poor chance of yielding samples in this range.

Cumulative frequency distributions can be drawn for each node on the grid; results are shown here for two sites. One location is in a region of relatively high average sulfur content, and of relatively high probability of samples lying between the 1.5 to 2.3% limits (fig. 9, curve A). A second location has a mean in this range, but only because of the nearly constant probability of high-sulfur samples across the area; the bulk of the curve lies below 1.5% sulfur and in fact there is a very low likelihood of encountering sulfur percentages between these limits (fig. 9, curve B).

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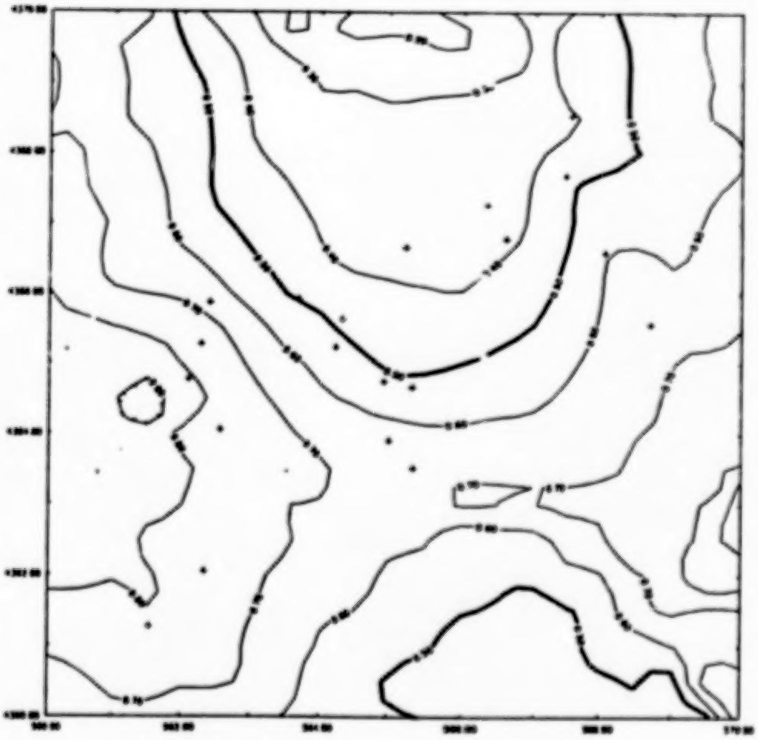

Figure 6. Probability of sample exceeding 1.4% sulfur.

Figure 7. Probability of sample exceeding 2.7% sulfur.

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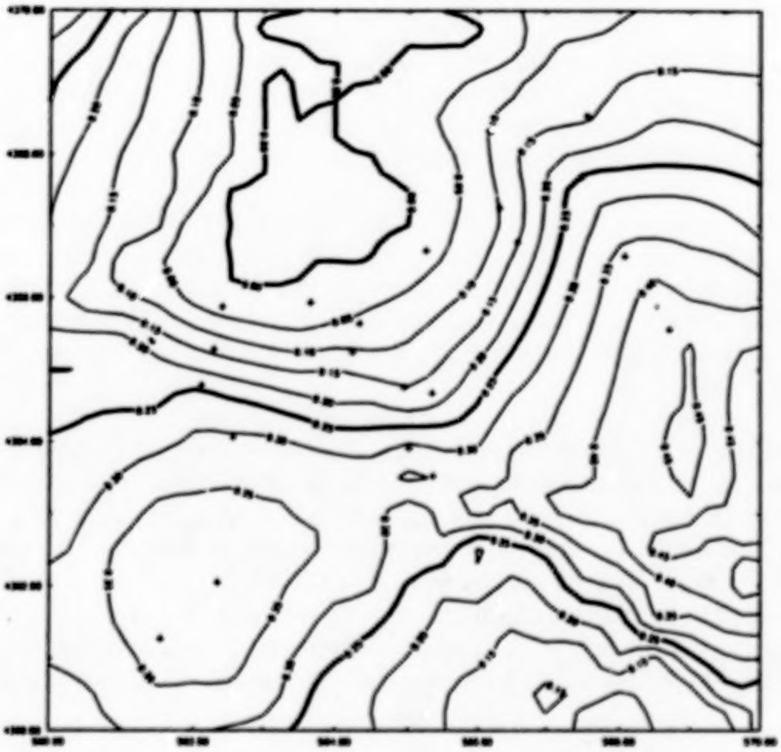

Figure 8. Probability of sample falling in a range of 1.5 to 2.3% sulfur.

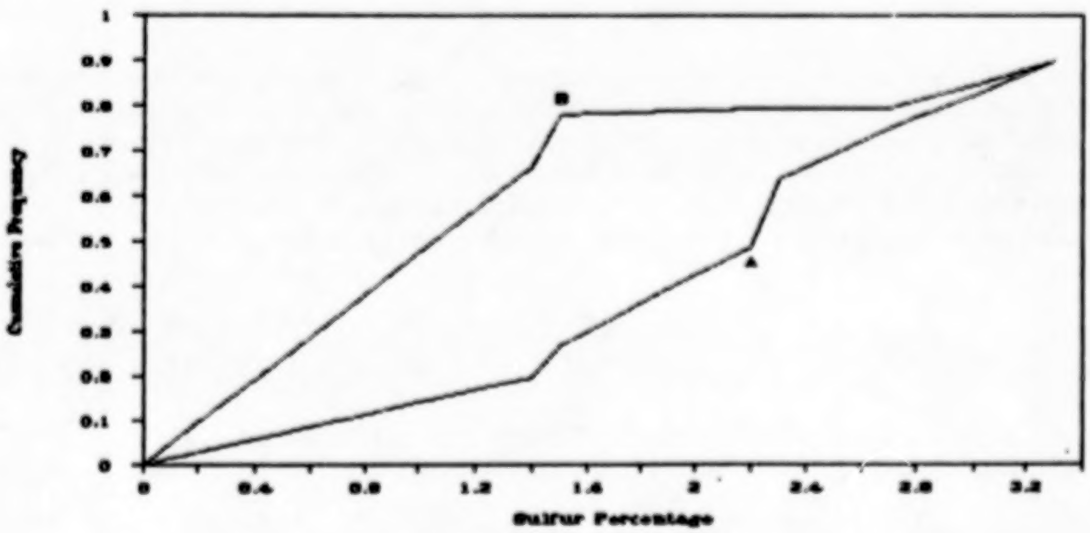

Figure 9. Relative cumulative frequency plots for sulfur at two locations in study area. Location A is 562 km east and 4363 km north; location B is 565 km east and 4368 km north.

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4. DISCUSSION

Nonparametric estimation is relevant to a number of Survey activities that use coal quality data: teaching geologists with minimal statistical background how to use geostatistics in mapping, developing a database of coal quality information, and providing appropriate maps to specific requests for information.

Geostatistics has always appeared difficult to the novice. Most geologists unfamiliar with statistical methods would prefer to contour by hand. However, the need to provide for information more rapidly, as "customers" come to the West Virginia Geological and Economic Survey seeking the whereabouts of coal of their grade-requirement, has prompted many of these geologists to seek other speedier, but yet accurate methodology.

The problem of training geologists to use kriging becomes even more difficult if in addition to learning how kriged estimates are calculated, the geologist must learn how to use estimation variances to compute probabilities, or to use methods such as disjunctive kriging. Not only does the nonparametric approach result in direct computation of probabilities, but gives a type of information that would be hard to contour by hand. Other than the mechanics of computation, the one concept new to geologists is the semivariogram. Experience at the Survey has shown that a spreadsheet program with graphics facilitates understanding by making the onerous job of fitting semivariograms very easy.

The West Virginia Geological and Economic Survey is currently restructuring the coal quality database, adding new information for samples collected from areas only sparsely samples in the past, and checking all data for error. Kriging is to be used in the error-checking process by comparing each analysis against a local frequency distribution computed from other samples in the same seam and geographic neighborhood. Thus, non-parametric estimates will be used to flag unusual analyses before they reach the database, and to spot such data added in the past.

Finally, the Survey wants to provide as many tools as possible to the person wishing to locate coal to be mined with certain specifications. In the past, these tools have been maps showing locations of samples meeting specified limits, and contour maps of expected mean values. Risk-qualified maps provide yet another tool to help producers assess areas within the state. Because West Virginia has coals that range widely in quality, making such information readily available should attract potential users to the state.

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QUANTITATIVE DIMENSIONS OF NEIGHBORHOODS FOR COMPARATIVE RESEARCH

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ABSTRACT

Modern urban neighborhoods, defined by supermarket patronage, have about 5,000 to 20,000 people. Variables of definition form an equation which inputs variables like area, lot and block sizes, local shopping demand, and demographics and yields, for example, travel times and distances (car trips for low density and noncar modes for high density). One goal is to compare accessibility in car/dispersed systems with that of noncar/dense systems. Accessibility in dense neighborhoods is also discussed using impressions from neighborhoods in America and Europe. Census tracts are analyzed for their neighborhood area, with an illustration from San Francisco.

1. INTRODUCTION

The social, economic, and environmental advantages of residential density have long been recognized conceptually but no neighborhood model has attempted to quantify the differences over a wide range of variables. While it is not possible yet to demonstrate, for example, a density tipping point for the efficiency of car versus noncar accessability, it is useful to develop prototypes for the two systems which are as comparable as possible except for density and travel mode. Since the same variables must be specified to describe each system, a neighborhood model can begin to be developed.

2. THE DEFINING EQUATION

The first step is to define prototype neighborhoods quantitatively. The major groupings of variables are land area, population, density, purchasing power, employment, floor area for residential, commercial, nonprofit, governmental and non-neighborhood uses, building characteristics, lot characteristics, street size, transportation characteristics, and site plan. Most of the terms used in this paper are discussed more extensively in <u>Neighborhood Systems</u> (<u>NS</u>) 1:2 June 1986. The kind of detail used to define a system in any given specific analysis depends to a great extent on which of some two dozen evaluative criteria will be applied to that system. At this stage, my primary research focus is on accessibility, so the equation developed here will have that primarily in view. However, the steps of analysis

can be repeated for other criteria.

For accessibility analysis we need to know trip making behavior of households, and the distances and speeds traveled. This data can be used to evaluate the probable performance of prototypes. The performance of a prototype neighborhood depends on its site plan and its travel connection with the other land use tiles of the mosaic which make up a city. The characteristics of the prototype constitutes the independent variables. The major dependent variable is the time needed to make the trips the household requires. An evaluation can then be made: How does prototype accessibility compare with existing household trips and with competing prototypes? Other evaluations could look at cost, safety, reliability, and ease of use of travel mode. The main evaluative criteria are the comparative travel times of the car and noncar systems, with the fastest system considered better. The independent variables can be presented as an equation, one form of which is presented below. The equation can take many forms depending on what variables the researcher wishes to stipulate first. These, as can be seen from inspection, would then limit or define the other variables. The variables listed below in brackets are not defined in this paper, but a more detailed model could define them. Specific data below is usually national averages, which define the suburban neighborhood prototype (SN) and, as much as possible, the pedestrian, or noncar, neighborhood prototype (PN).

The factors developed below are also presented in a spread sheet at the end of this paper.

2.1 Summary

Number of people using various factors yields operative floor area needs (residential, business, non profit), divided by average number of stories of building height = building ground coverage.(Operative means relevant for the analysis. In the SN floor area is not operative, only land area; in a PN floor area is operative for most uses.)

Building coverage + a factor times building coverage for unbuilt lot area = lot area for buildings (LAB)

LAB + operative land area needs (residential, business, nonprofit; schools, parks) = total lot land area, divided by average block size = # of blocks.

One half perimeter of block minus one street width, times street width times # of blocks = street area

Total lot land area + street area = total neighborhood area (TNA)
square root of TNA = longest distance (outside corner to center)
.7 times square root TNA = average distance (one-half-of-area line to center or modal residence distance to center)

Distance to purpose (eg center) times average speed = travel time
(External trips--outside the neighborhood--not estimated.)

2.2 Specifying Variables Common to PN and SN

Demographic: 10,000 residents, 2.69 average household (h'd) size, 3,717 h'ds [age/sex distribution; h'd size distribution; h'd types:

example of types: U.S. 1984	thousands	percent
elderly (65 and over) singles	7,966	9.3
elderly head, 2 or more in h'd	9,969	11.7
singles under 65	11,988	14.0
two person with no children under 18	16,551e	19.4
3 or more with no children under 18	7,887e	9.2
couples with children under 18	24,340	28.5
singles with children under 18	6,706	7.9
total	85,407	100.0

Source: Statistical Abstract 1986 pp 39-47
Note: if a prototype were to follow the national patterns, it would have to have these percentages of h'd types.)]

Economic: [per capita income, average h'd income, h'd income distribution; disposable income per capita; total neighborhood disposable income for routine (frequent, short trip, local, neighborhood) business; adjustments to demand due to locals shopping out and non-locals shopping in; neighborhood employment, distribution by occupation and industry, distribution by local vs basic; day time population, distribution by labor force status, and resident/-non-resident status]

Education: 3 K-8 schools, 460 students average, 1,380 total; no high school

Floor area variables:
residential: 558 square feet of residential space per person x (10,000 persons + 300 for vacancies)= 5,747,400 total sq ft [sq ft/h'd, distribution of units by sq ft; other interior amenity measures; sq ft derived from a table of income against h'd types]
business: 150,000 sq ft [list with # and type of business, sq ft of each type (details in NS 1:3)] [calculations from disposable income and competing commerce to #, type, square footage]
nonprofit: 50,000 (preliminary estimate of 1/3 of business)
total floor area = 5,947,400

Trip variables: tables showing purpose and frequency of trips:

DAY TRIPS (mostly routine, frequent, and short)	Nation: millions /year	Neighborhood: #/week /10,000	percent	Average miles /trip	Percent - total miles
total	224,385	239,325	100.00%	8.13	100.00%
work	45,826	48,877	20.42%	8.54	20.11%
work-related business	5,283	5,635	2.35%	21.88	5.94%
shopping	40,655	43,362	18.12%	5.39	11.26%
family or personal business	36,158	38,565	16.11%	7.11	13.20%

school/church	26,486	28,249	11.80%	4.91	6.68%
visit friends or relatives	24,743	26,390	11.03%	11.46	14.56%
other social / recreational	35,457	37,818	15.80%	8.52	15.52%
vacation	630	672	0.28%	246.91	7.99%
other	9,147	9,756	4.08%	10.09	4.74%
LONG TRIPS (over 100 miles, mostly special, infrequent, and long)					
total	1,012.0	1,079	100.00%		
visit friends and relatives	384.5	410	37.99%		
other pleasure	349.7	373	34.56%		
business or convention	156.1	166	15.42%		
other	121.7	130	12.03%		
total or average	1,012.0	1,079	100.00%		
vacation trip	689.6	736	68.14%		
weekend trip	434.9	464	42.97%		
mode:					
car (inc. truck, rec. vehicle)	794.0	847	78.46%		
airplane	174.5	186	17.24%		
other	43.5	46	4.30%		
	1,012.0	1,079	100.00%		

Notes: 1983 for day trips; 1984 for long trips. Total person miles traveled for day trips = 1,946,662. Stat. Abstract is wrong on p 604, table 1056, person # of trip shows 15,283, should be 5,283. Miles traveled not available for long trips. The population is household population 15 years and older in 1984 (180,303,000). Weekly neighborhood trips are based on total annual trips divided by the population (= per capita), divided by 52 weeks, multiplied by 10,000 people.
Source: Derived from Statistical Abstract 1986 p 42, 604, 605.

2.3 Calculation for Noncar Prototype (PN)

Floor area needs of 5.95 million total sq ft floor area divided by 3 (average number of stories) equals 1.98 million sq ft of building ground coverage. [Could be based on a more complex approach, designing various units for various types of households, various buildings to accommodate the units, various lots on which to put the buildings, etc., or measuring an actual neighborhood.]

Building coverage 1.98 m sf + a factor of 50 percent to estimate for unbuilt lot area equals 2.97 m sf lot area for buildings (LAB)
Land area needs: 3 schools with parks: 5 acres each, 15 total, = 653,400 sq ft. equals total lot land area of 3,627,100 sq ft.

Average block size = 200 by 1000 feet, 200,000 sq ft per block, about 5 acres, divided into total lot land area (3,620,000) = 18.1 blocks.
Street area: One half perimeter of 1200 minus one street width of 35

feet = 1160, times street width of 35 feet times 18.1 blocks equals street area of 739,475 sq ft
Total lot area 3.62 million sq ft + street area .84 million sq ft = 4.37 million sq ft Total Neighborhood Area, or 100 acres.
Longest distance, square root of TNA, = 2,111 feet
Average distance, .7 times above, = 1,478 feet

Land Use [site plan: siting of buildings on lots in neighborhood]
Density = 10,000 people divided by 100 acres = 100 persons / gross acre

Travel modes to out of neighborhood destinations
1. major employment centers: by transit to central business district or industrial area
2. regional shopping: by transit downtown
3. hospital: by transit
4. high school: walk
5. long trips: by car rental, air

2.4 Calculation for Car Prototype (SN)

Since floor areas are not operative, all uses are specified in lot areas. For residential, lot area equals 5,000 square foot average, times 3,717 h'ds equals 18,585,000 sq ft. For business using old parking ratios the area would be four times the gross leasable area, or 600,000 sq ft (13.77 acres), but more recent practice would indicate 10 acres for a community shopping center and other business, or 435,600 sq ft. Nonprofit, at one third the business area, would be 145,185 sq ft. Each school / parks will be 6 acres, which adds one acre for parking to the 5 acres assumed for the PN; for three the total is 18 acres, or 784,080 sq ft.

Total lot land area equals 19,949,865 sq ft. Lot size can remain the same, allowing 40 lots at 50 by 100 each per lot as a suburban average for the range from estate lots to two story apartments. Total number of blocks is then 99.7 blocks.

One half the perimeter is still 1200 feet but the street width will be 60 feet, based on two travel lanes at 12 feet each, two parking lanes at 10 feet each, and sidewalk, utilities, planter strip, and adjustments to grade of 8 feet each side. Then 1140 times 60 feet times 99.7 blocks = 6,819,480 sq ft for street area.

Total Neighborhood Area is 26,770,000 sq ft, or 615 acres.
Longest distance = 5,174 feet, about a mile
Average distance = 3,622 feet.

Density = 10,000 divided by 615 acres = 16.3 persons per gross acre

Travel modes to out of neighborhood destinations
1. major employment centers: by car to central business district or

industrial area.

2. regional shopping: by car to big shopping mall
3. hospital: by car
4. high school: by car
5. long trips: by car, air

3. THE DEPENDENT VARIABLE: ACCESSIBILITY

3.1 Internal Travel

Internal trips are so short that little things count, e.g., the time it takes from closing the front door of the house to getting in the car to starting to move, and, at the other end, from the car to the entry of work, school, shopping, etc. This "in-out" movement seems to take about three minutes altogether. The longest internal suburban trip in the prototype, about a mile, at 20 miles per hour average speed would take 3 minutes for the car portion and 3 for the in-out portion, or about 6 minutes. The longest internal noncar trip in the PN was 2,111 feet at three miles an hour walking takes 8 minutes

3.2 External Travel

Longer trips in the SN have higher speeds because they can generally use freeways, but greater distances add to time. If congested, the time is longer. Congestion is predictable: peak hour in peak direction. Generally, however, there is a smooth correlation between time and distance. In the PN, the external trip uses transit or car rental. Both have equal access to airports.

3.3 Comparative Accessibility, PN and SN

The internal travel time estimates show how close the two prototypes are. By playing with the entries in a spread sheet, the outcomes can be made equal. Using the assumptions used here, suburbia has a slight edge on a noncar prototype for the longest internal distance. Since the in-out time is constant, the PN is, in this particular illustration, closer to the SN time for the average distance. The internal travel time stands as a proxy for the shorter trips: school/church, shopping, family/personal business, and other social/recreational. Research is needed to quantify the many reasons why surveyed day trips are so much longer than the trip to the center of the SN. The shortest trip, 4.91 miles for school and church, would take 17.8 minutes at 20 mph and 3 min. for in-out. This time compares very poorly with 8 minutes in the PN.

What about the PN, though; would it also have slower real times than suggested by the prototype? Unlike the SN, the PN does not have much potential to make the "internal trip" longer without abandoning the definition of what a PN is. There seems likely to be some erosion of the travel time, however, mainly because people are likely to travel

outside the PN to meet their needs, just as people in SN. In this context acceptable travel time is probably more a controlling feature than mode. An important point, however, is that reasonable travel time to shopping of 8 minutes from the farthest corner to the center of a PN is significantly faster than current times in suburbia.

The typical longer day trip is the work trip. Other research has shown comparable work trip times between suburbia and those living in the high density housing belt north and west of downtown San Francisco. A PN fully justifies transit--probably unsubsidized--because of high use rates and short distances. The work-related business trip is not a neighborhood based trip and so may seem unrelated to the issue, but some people drive who could take transit because of errands they need to do while at work. In this case, it is the role of noncar modes in the center or work place which are important. Denser, pro-transit centers allow people to do these errands without a car.

The trip to visit friends or relatives is longer than the short day trips, and shorter than the work trip. It is also important for quality of life, and one that the PN will have problems dealing with because of the diversity of locations and how much they change. It raises the issue of the cost in time of changing modes in the PN. Travel within the PN is short in time and pleasant and reaches many objectives. However, trips outside require a longer walk, waiting for transit, or renting a car. The waiting time and renting time are the time cost of mode change. For short trips it does not occur; for longer trips it does not matter; but for intermediate trips the car may have some advantage. Much will depend on the efficiency of transit and car rental/storage in the PN prototype.

For a discussion of two household surveys of trips, one of suburbia and one of a dense neighborhood in San Francisco, see NS 2:2 October 1987. The conclusion was that the trip frequencies and times between the two system were very similar despite very different modes used and distances traveled.

Long trips are a fraction of the number of day trips, 1,079 per week per 10,000, which is only .45 percent of the day trip figure of 239,325 per week per 10,000. They also last longer and use auto and air modes. People in the PN would rent cars at the interface of their neighborhood and the car-dependent world, or they would take transit to airports. In either case, overall trip time is likely to be the same as suburbia.

4. NEIGHBORHOODS

4.1 In the United States

Several American cities have neighborhoods of the density required to have noncar modes than can match the accessibility of suburbia. An

arc of dense neighborhoods (over 60 persons per acre) from north to west borders downtown San Francisco: North Beach/Telegraph Hill/North Point, Chinatown, Russian Hill, Polk Gulch, Nob Hill, Tenderloin (the densest), Western Addition (part), Hayes Valley and Inner Mission. The Marina, Pacific Heights, Cathedral Hill, Duboce Triangle, Dolores Triangle and parts of the Western Addition, Outer Mission, the - Haight, and Richmond also have medium to high density. In Boston, Back Bay-Beacon Hill is especially interesting as a large, dense, high middle to upper income area. In Washington D.C. the Adams Morgan area is interesting for its mixed incomes.

New York has dozens of dense neighborhoods, mostly on Manhattan, some of which are high rise. While some cities have high rise housing, only New York has high rise neighborhoods. New York's five story row houses on the numbered streets generally have very pleasant street environment. The high rises, however, are on the broad avenues, which are often congested or have fast traffic. Compensating for these problems are abundant shopping within easy walks and subway access to countless other city places. The Manhattan experience seems to me the most intense of any city in the world, with more access to more things, but not much peace and quiet. I have yet to find a survey of household travel for these dense neighborhoods.

4.2 In Europe

In the summer of 1985 I looked in several European countries for dense, middle class neighborhoods. The places I looked at were New Town and Warrender Place in Edinburgh, Pimlico in London, Quartier Archives in Paris, Zermatt in Switzerland, Caravalho in Venezia, Osterbro in Kobenhavn, Ostermalm and Vasastaden in Stockholm, Oude Westen in Rotterdam, Delft Centrum in Delft, Jordaan in Amsterdam, Uhlen Horst in Hamburg, Ruttenscheid in Essen, Agnes Viertel in Koln, Innere Nordstadt in Bonn, Sachsenhausen and Ostend in Frankfurt, and Josephplatz in Munchen.

Zermatt and Venezia used noncar systems. Zermatt permitted a limited number of electrocarts for freight, each hotel or major business owning one, and a few taxis. One of the hotels kept a horse and carriage for service from the train station at the end of the line. Bicycles were not much used. The roads were few and narrow--along the river and through downtown, with some connectors. There were many paths, passageways, and narrow driveways. The dominant form of construction was a chalet style finish to a modern cement and steel core. Chalets were clustered in the central area, where walking distances were short. Some, however, were some distance from the center, with long walking distances. For vacationing visitors each chalet was fairly self-sufficient, and the walks acceptable, as is true of resorts elsewhere. For owners, the electrocarts could be used for personal trips. Others, I think, lived close to work. Zermatt is rich in natural mountain scenery, and the lack of cars adds to the

relaxed atmosphere. Zermatt brochures advertise the lack of cars.

Venezia is very different--flat, damp, intensely built-up, historic. The only things in common with Zermatt is that both have parking structures for cars at their entrances and both consider accommodating cars unthinkable. Venezia's main routes are wide canals serviced by vaporettos, or medium sized fast passenger boats. The picturesque gondolas are for tourists. Electrocarts won't work because the roads--sidewalks between buildings--are too narrow and because of bumpy bridges over numerous small canals which interlace the islands. These canals are used for freight and small boats. The main routes also include certain sidewalks whose width varies erratically but which provide the main walking routes down the spines of the islands. These routes are usually lined with shops and, space permitting, open air markets. Minor sidewalk routes feed into main routes and serve areas between the small canals. The main sidewalks can become quite congested. The minor routes and some out-of-the-way courtyards, by contrast, are surprisingly uncongested, virtually unused for much of the day. The low rise (three to five story) construction achieves density by minimizing open space--less is open than any other city I saw. Relief is provided by the piazzas and views of the open water of the grand canal and of the lagoon. From a car point of view, the little streets are too narrow and the big streets are too wet, but Venezia nevertheless provides easy accessibility.

The other middle income dense neighborhoods achieved high density through medium rise buildings of about five (Amsterdam) to seven (Paris) stories on medium to wide streets (compared to Venezia). This extra width was almost always overcrowded with parked cars,often parked over the curb, on the sidewalk, or in green spaces, which reduced considerably the quality of the neighborhoods. On a few arterials, some very narrow, fast traffic destroyed street amenity. Yet there was little traffic on most streets. It seemed that everyone used transit for central jobs and shopping, and walking for local shopping; the car was for special trips. Often trees and attractive buildings could reduce the negative impression caused by ground level congestion. Denmark and Nederland had remarkably high bicycle use and good bicycle facilities. In all cases, transit and local shopping were abundant, providing high apparent accessibility. Data I collected will allow some quantification of densities. distances, and walking times, but information is needed on commerce, transit times, and household travel in dense areas.

5. CENSUS TRACT ANALYSIS: SAN FRANCISCO

5.1 The Land Use Data

In June 1973 the San Francisco Department of City Planning published San Francisco Land Use Tabulations for 1970, which presented for each census tract in the city land use data for 40 uses to the nearest

hundredth of an acre, that is, within 435 square feet accuracy. My goal was to make a close estimate of gross residential area in order to calculate gross densities, commerce to residential relationships, and walking distance. I assumed there was not much change in land uses over the 1970 to 1980 period, which seems valid for the denser, older residential areas.

Since the tabulations looked only at ground floor use, commercial with residential above was not distinguished from commercial without residential. This complicated figuring out how much area was residential, so I assumed that all "retail and office" had residential overhead except in the downtown tract. Also, in a few cases tourist hotels or other nonlocal uses were excluded. In practice, very few tracts posed much of a problem. Generally, the total of residence, retail and office, institutional, and city uses was considered residential. Excluded were gas stations, parking garages and lots, industry, utility, noncity public, and vacant land uses. Using these figures I adjusted the net acreage of the census tract from all uses to residential uses. I applied the ratio of net residential acres to total net acres to find what percent of the net area was residential. I applied this percentage to the street area, and combined net residential area with residential street area for total gross residential acres. Finally, I could see the population density of the gross residential area of each census tract.

In 7 of 68 dense tracts, adjustments caused increases in density from unadjusted to adjusted of over 100 percent, and in 7 more, adjustments between 50 and 100 percent. For example, the civic center tract includes 30 acres of central institutional uses--cultural buildings, city hall, state and federal offices, and a park. Unadjusted, this tract appears to have 47 people per acre. Adjusted, it has 122 per acre. If some commercial buildings could be properly allocated to central uses, the density would be higher. More typical is the "Nob-erloin" tract (between Nob Hill and the Tenderloin), with an apparent density of 115 but an adjusted density of 132. By this careful analysis of 68 tracts known to be relatively dense, I was able to identify the most dense for further research.

A better approach would be to classify lots by residential or central uses, to delineate a line between generally residential and generally central areas, and to see how much mixed use there is in each area. My impression from walking the city is that this is practical to do, and is important for analyzing accessibility in real neighborhoods and in developing prototypes.

5.2 Demographic and Other Data

The Census provides the most data of any source, yet becomes difficult to use for certain data at the tract level. I was able to access census tapes, mostly STF 3, at the State University Data

Center (SUDC) in Los Angeles via computer from Hayward, and to pull data from them using Censpac software. While Censpac was user-unfriendly, it allowed me to find the number of car-free households, number of units in structure, and number who commute alone to work. Using these figures, converted into percentages, I constructed an index of pedestrianization potential. Percent dense structures plus percent car-free minus percent commuting alone to work equalled the index. About 50 tract had indexes over 100. The index for the state of California was minus 20.6, showing how different these tracts are from the average. In other work I found five census tracts with over half their households being car-free and with per capita incomes at or above the state average (e.g., Noberloin).

However, I was unable to pull useful data on building height. What is needed are figures for buildings 3 or more stories high with residential use. The census also lacks information on the area of tracts, let alone land uses within them. Dense tracts are only found in a few big or old cities. If we are to understand dense modern neighborhoods, we need to find them. Even without area data, I was able to identify probable tracts using other census data, and then get more precise data using the San Francisco tabulations with the census. This kind of work needs to be done in other cities, as well as getting more relevant data to begin with.

6. THE RESEARCH AGENDA

Little if any basic research has been done on modern neighborhood systems. Actual neighborhoods are tending world-wide toward greater car dependence with no competition, theoretically or practically, from noncar alternatives, although a few individuals function using noncar modes in car-impacted neighborhoods. Yet car systems have considerable costs in loss of wild and agricultural land, preemption of urban space, congestion, energy, pollution, resource consumption, infrastructure, utilities, service distances, health, safety, public aesthetics, street social amenity, community spirit, and possibly even in accessibility. The alternative, a noncar neighborhood, is a large, and therefore difficult, social invention, and one which requires density with quality and restraint on a personal proclivity to use cars. Such restraint must be based on a recognition that it improves accessibility for all. To attain that recognition, research on neighborhood design and evaluation needs better quantification. For example, just for accessibility, computer modeling of the SN and PN prototypes, better household travel statistics, and better land use data for neighborhoods are needed.

Rational argument can play a role in establishing if and when noncar modes are superior, and in encouraging practical experimentation involving residents of existing dense neighborhoods in decisions to evolve towards a superior form of travel. Such argument can only be developed if investment is made in neighborhood systems research.

Spreadsheet: Quantitative Dimension of Neighborhood Systems

	A	B	C	D	E	F	G	H
1	QUANTN: CALCULATIONS PN VS SN				feet, square feet			
2	BUILDINGS:				sf/p	sf/h	total n	acres
3	people	10,000		res sf/p	558	1,501	5,747,400	131.9
4	household	3,717		bus sf			150,000	3.4
5	h'd size	2.69		nonprofit			50,000	1.1
6				total			5,947,400	136.5
7	PN LAND AREA:							
8	buildings: stories		3	coverage			1,982,467	45.5
9	unbuilt lot area		0.50	Lot Area -	Buildings:		2,973,700	68.3
10					#	size each		
11	land area needs	school/parks			3	217,800	653,400	15.0
12	total lot land area						3,627,100	83.3
14	block size	200	1,000	200,000		# blocks	18.14	
15	streets width:		35	area:			739,475	17.0
16	Total Neighborhood Area						4,366,575	100.2
17	gross density		100	people	per acre			
18	longest distance		2,090	average	distance	1,463		
19	walking speed, mph		3					
20	walking time, min.		7.92	average	time	5.54		
22	SN LAND AREA:							
23	res lots	50	by	100	5,000	total	18,585,000	426.7
24	bus						435,600	10.0
25	nonprofit	0.3333	of bus				145,199	3.3
26	school/parks		217,800	+ pkng	43,560	261,360	784,080	18.0
27	total lot land area						19,949,879	458.0
28						# blocks	99.75	
29	streets width:		60	area:			6,822,858	156.6
30	Total Neighborhood Area						26,772,737	614.6
31	gross density		16					
32	longest distance		5,174	average	distance	3,622		
33	driving speed		20	in/out	3 min			
34	driving time		2.94			2.06		
35	total time, min.		5.94	average time		5.06		
37	ratio PN/SN		1.33			1.10		

Cells with hidden formulas:

F3- E3*B5
G3- (B3+300)*E3
H3- G3/43560
H4- G4/43560
B5- B3/B4
G5- .333333*G4
H5- G5/43560
G6- SUM(G3:G5)
H6- G6/43560
G8- G6/C8
H8- G8/43560
G9- G8+C9*G8
H9 - G9/43560

F11- 5*43560
G11- E11*F11
H11- G11/43560
G12- G9+G11
H12- G12/43560
D14- B14*C14
G14- G12/D14
G15- (B14+C14-C15)*C15*G14
H15- G15/43560
G16- G12+G15
H16- G16/43560
C17- B3/H16

C18- SQRT(G16)
F18- .7*C18
C20- C18/(C19*5280/60)
F20- F18/(C19*5280/60)
E23- B23*D23
G23- B4*E23
H23- G23/43560
G24- 10*43560
H24- G24/43560
G25- B25*G24
H25- G25/43560
C26- F11
F26- C26+E26

G26- F26*3
H26- G26/43560
G27- SUM(G23:G26)
H27- G27/43560
G28- G27/D14
G29- (B14+C14-C29)*C29*G28
H29- G29/43560
G30- G27+G29
H30- G30/43560
C31- B3/H30
C32- SQRT(G30)
F32- .7*C32
C34- C32/(C33*5280/60)
F34- F32/(C33*5280/60)
C35- E33+C34
F35- E33+F34
C37- C20/C35
F37- F20/F35

A SYSTEM FOR INVENTORYING THE LAND RESOURCE POTENTIAL OF TROPICAL WATERSHEDS

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University of Florida

ABSTRACT

This paper describes a method for assessing the land potential for agroforestry systems in tropical steeplands. The system combines stratified random sampling to locate observed field sites, air photo interpretation, data processing, and computer cartography. Environmental stress is identified through an analysis of land use change while a land use compatibility rating is obtained by matching physical site properties with agroforestry land requirements. A Caribbean case study demonstrates the system's application.

1. BACKGROUND

This paper presents a method to assess the land potential for agroforestry systems in tropical steeplands. It is designed for regional planning and field implementation scales. The testing and application of the system was carried out in the Las Cuevas basin (573 km2), Dominican Republic, where ecological problems abound, including accelerated soil erosion, deforestation, and downstream sedimentation. The effects are diminishing soil fertility and land productivity, as well as a reduction in the viability of downstream water storage and hydroelectric facilities, investments which countries like the Dominican Republic must rely on for energy generation and irrigation capacity.

2. OBJECTIVES

The specific objectives of this research were: to develop a method to analyze the relationship between land use change and resource potential in tropical steeplands; to apply this method in the Las Cuevas basin by identifying areas of environmental stress related to land cover and site quality; and to recommend short, intermediate, and long-term natural resource management strategies for the basin.

3. ENVIRONMENTAL QUALITY EVALUATION

Information on soil and land surface properties was obtained from a 15% sample of 1/4 km2 cells, randomly selected, stratified, and areally weighted according to geomorphic regions. Data from the 350 cells were collected on 43 variables at 1/100 km2 sites, randomly selected from 25 sites within each cell. Site data then were considered representative of the 1/4 km2 cell.

The data collection method relied on field observations and materials for laboratory analysis. The variable set was reduced to 19 diagnostic ordinal variables, after screening for frequencies, multiple correlation analyses, and importance in the local agroforestry system. Evaluation of environmental site quality followed a multi-stage procedure. The range of each variable was reviewed and divided into five response class intervals which were subsequently ranked as 5 quality classes from lowest "1" to highest "5". Values of each site variable were read from the raw data file and assigned to the corresponding quality class. Quality class rankings for the 19 variables were summed to obtain a site score. Summed site scores were ranked for their combined properties and placed into 5 levels of overall land quality (1).

The summed scores were interpolated from the observed sites to the unobserved sites using the SYMAP computer cartographic program which applies an inverse-squared distance weighting function to reduce the influence of distant data points (2). Figure 1 was compiled using the summed scores of the 19 rated quality class variables and shows the spatial distribution of the 5 levels of land quality in the watershed. Level 1 is considered non-agricultural land and accounts for 23.30% of the watershed. Level 2 land covers 28.45% of the watershed. It is considered poorly suited for agriculture, principally, because of its moderate to high relative relief and moderately shallow soils. Intermediate quality level 3 land accounts for 29.32% of the watershed area. Levels 4 and 5 are considered good to prime agricultural lands. They account for 18.85% of the watershed.

4. LAND COVER ANALYSIS

The analysis of land cover change was based on a comparison of 1958 aerial photography and the 1982 field survey. The 350 field sites were located on 1:55,000 scale imagery. A land cover scheme devised for the interpretation has 6 categories: crops, excluding coffee; improved pasture and native grass

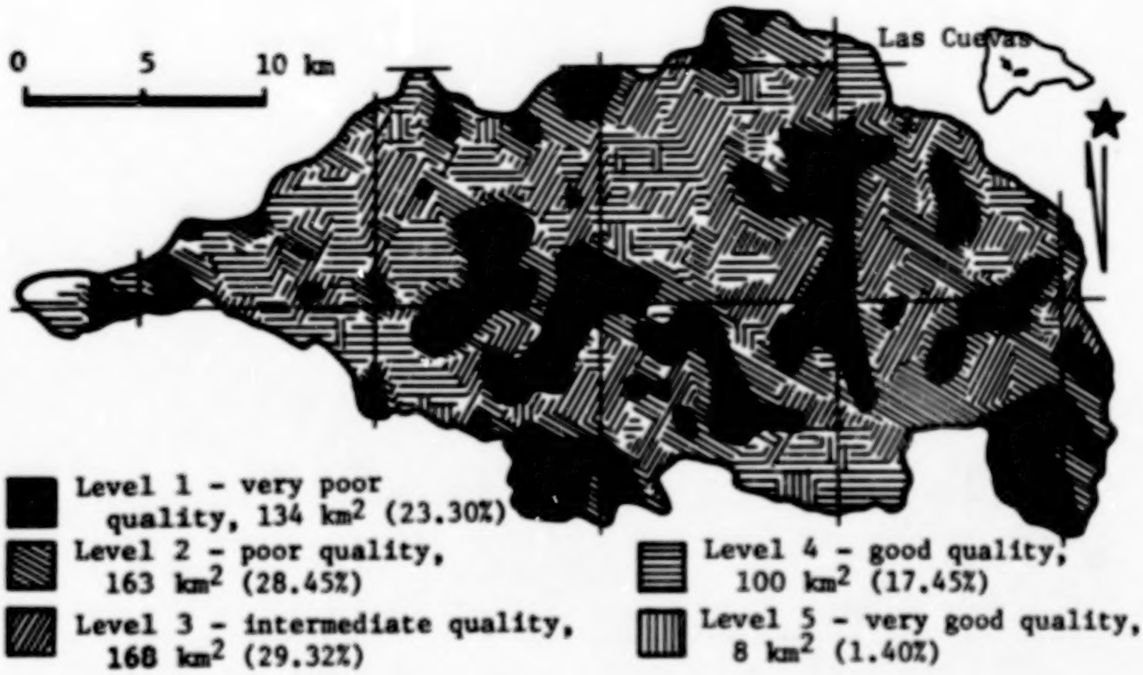

Figure 1. Site quality evaluation.

land; improved pasture, native grassland and trees; coffee with shade trees; forest; and areas without agricultural use or forestry (non-use).

Computer maps of general land cover for 1958 and 1982 were produced using a proximal mapping algorithm which assigns to an unobserved site the land use of the nearest observed site. Interpolated and observed land uses were stored in a file and frequency distributions of 1958 and 1982 general land cover were obtained for all sites in the basin. Frequency site counts were converted to area measurements (km2) for each general land cover class in each year (table 1). The following changes in land cover are detected: a major increase in areas of non-agricultural and pasture-grassland categories; a moderate increase in cropland area; a major decrease in the pasture-grassland-trees and forest areas; and a slight increase in the shade coffee area.

5. ENVIRONMENTAL STRESS

Change in land use intensity was scaled, progressing from crops (highest intensity), pasture-grassland, pasture-grassland-trees, shade coffee, forest, to non-agroforestry

Land Cover	Area (km2)* 1958	1982
Non-use	0.64	32.52
Crops	111.42	127.68
Pasture	74.39	122.81
Pasture/Trees	133.33	53.02
Coffee	30.90	36.56
Forest	222.31	200.40
Total	573.00	573.00

*Data derived from 1958 and 1982 land cover maps

Table 1. Land cover areas in 1958 and 1982.

use (lowest intensity). A new classification was derived from the environmental stress-related categories: no change, increase in use intensity, decrease in use intensity. Land cover change, for example, from forest (1958) to crops (1982) was considered to represent an increase in use intensity; a change from pasture (1958) to forest (1982) would be a decrease in use intensity. Figure 2 shows changes in use intensity over the 1958-1982 period. This analysis offers a qualitative scale to measure changes over time in the stress relationships.

6. COMPATIBILITY RATINGS

Compatibility analysis examines the ratio between two corresponding sets of parameters: the natural site; and the site requirements of the agroforestry system. Each combined land cover and site quality category was rated as under-utilized, compatible, over-utilized, non-use. In this scheme (table 2), cropping on levels 1,2,3 is over-utilization; cropping on levels 4,5 is compatible use. The four ratings are defined qualitatively and suggest relative degrees of over-exploitation and under-utilization of the region's natural resources.

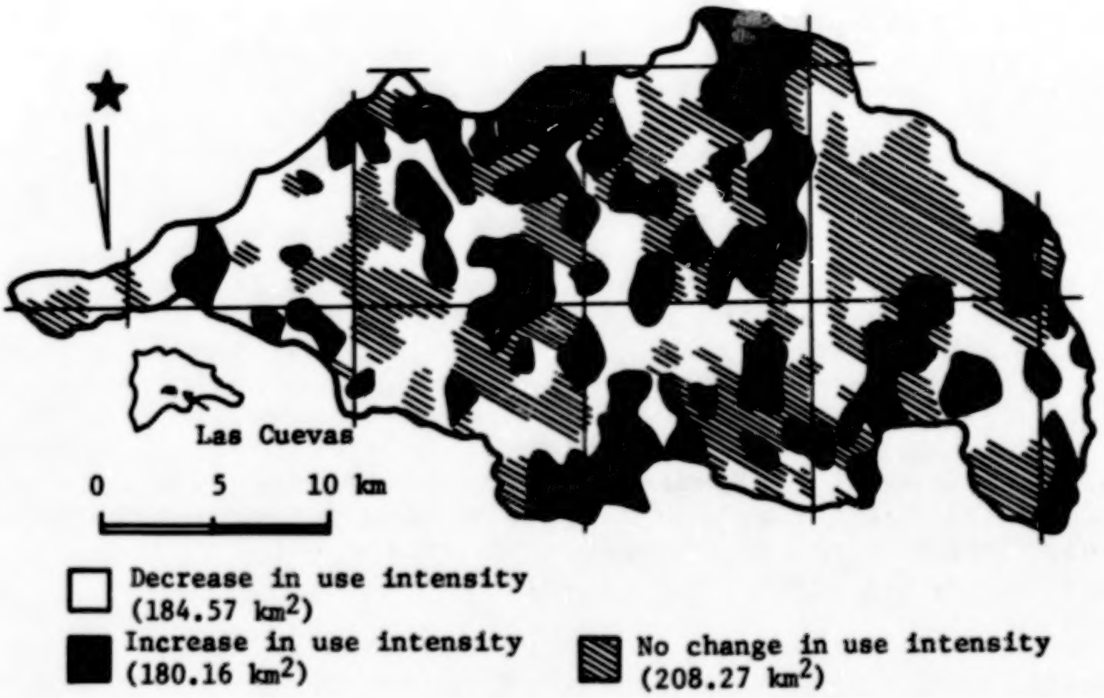

Figure 2. Change in land use intensity between 1958 and 1982.

Land Cover	Site Quality Levels 1	2	3	4	5
Crops	OE	OE	OE	CO	CO
Pasture	OE	OE	CO	CO	UU
Pasture/Trees	OE	CO	CO	UU	UU
Coffee	OE•	CO	CO	CO	CO
Forest	CO	CO	UU	UU	UU
Non-use	NU	NU	NU	NU	NU

OE-Overexploited; CO-Compatible; UU-Underutilized; NU-Non-agroforestry use

• Shade coffee is considered compatible use on Level 1 sites with slopes less than 60% and soil depth more than 10 cms.

Table 2. Compatibility ratings for combined land cover/site quality units.

Table 3 presents comparative area statistics by site quality level for both years. Over-utilized areas accounted for one-third of the basin during this period (28.61% in 1958, 30.49% in 1982). Compatible use areas accounted for nearly one-half; under-utilized areas amounted to approximately one-fifth of the surface area. Non-use areas were negligible in 1958 but expanded to 5.66% of the watershed in 1982.

Compatibility maps were compiled at several levels. A general map for 1982 shows the distribution of the four compatibility classes (under-utilized, compatible, over-utilized, non-use) in the watershed (figure 3). A second stage analysis mapped each compatibility class by site quality level in each of the two periods of study. This aided in differentiating resource problem areas (over-exploited, under-utilized) and facilitated the identification of future land management zones. A third stage compared changes in the land area of each compatibility class between 1958 and 1982.

A worsening picture of resource depletion in Las Cuevas emerges from the regional analysis of land cover change and environmental quality (table 3). The decrease in level 1 over-utilized land is more than offset by the emergence of an equal area of non-use land, most of which is composed of

Site Quality Levels	Over-Exploited 1958	Over-Exploited 1982	Compatible 1958	Compatible 1982	Under-Utilized 1958	Under-Utilized 1982	Non-use 1958	Non-use 1982
(worst) 1	83.48	66.73	50.90	50.11	--	--	--	17.53
2	43.85	70.50	118.82	83.57	--	--	--	8.60
3	36.59	37.50	59.77	66.00	72.02	60.66	0.03	4.25
4	--	--	50.29	59.65	49.02	38.23	0.55	1.98
5 (best)	--	--	4.62	4.01	3.01	3.59	0.06	0.09
Totals	63.92	174.73	284.40	263.34	124.05	102.48	0.64	32.45
%	28.61	30.49	49.63	45.96	21.65	17.88	0.11	5.66

Data derived from maps of compatibility between land cover and site quality in 1958 and 1982.

Table 3. Compatibility class area changes during 1958-1982.

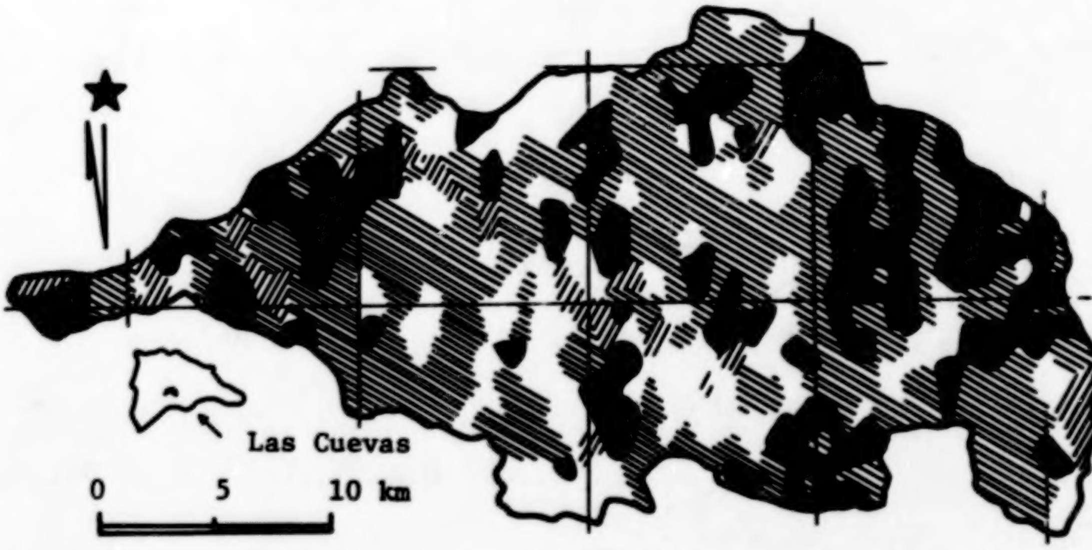

Figure 3. Compatibility of land cover and site quality in 1982.

soil-stripped alluvial terraces and floodplain sites. Over-utilized land on level 2 (poor) quality land increased dramatically from 43.85 km2 (1958) to 70.50 km2 (1982). Over-utilization of level 3 (intermediate) quality land remained constant over the period; it accounted for 37.50 km2 in 1982. Under-utilized areas in 1982 accounted for 102.48 km2 (17.88 percent) of the watershed; 60.66 km2 were situated on moderate quality (level 3) land, 38.23 km2 were found on good quality (level 4), while only 3.59 km2 of the prime quality (level 5) lands were under-utilized.

7. CONCLUSIONS

Land management strategies can be built upon this inventory system's application in the Las Cuevas basin (table 4).

1. Short-term: (a) reforest the 22.52 km2 of over-utilized level 1 land; (b) evaluate the feasibility of intensively farming the 3.59 km2 of under-utilized level 5 land.

2. Intermediate-term: (a) reforest the 34.30 km2 of cultivated and over-utilized level 2 land; (b) evaluate the feasibility of introducing farming systems into the 38.23 km2

1982 Land Cover	(worst) 1	Site Quality Area (km2) 2	3	4	(best) 5	Total
Non-use	--	--	--	--	--	
Crops	22.52(1a)	34.30(2a)	37.50(3c)	--	--	
Pasture	28.37	36.20 (3a)	--	--	1.33	
Pasture/ Trees	5.23	--	--	7.30	1.34	
Coffee	10.61(3b)	--	--	--	--	
Forest	--	--	60.66	30.93(3c)	0.92	
Totals						
Qty. Lvls.	66.73	70.50	98.16	38.23(2b)	3.59(1b)	
Over-used	66.73	70.50	37.50	--	--	166.60
Under-used	--	--	60.66	38.23	3.59	102.51

Data derived from 1982 land cover map and site quality map. Labels, e.g. (1a), refer to comments in the "conclusions".

Table 4. Over-exploited and under-utilized areas in 1982.

of level 4 quality lands.

3. Long-term: (a) reforest the 69.80 km2 of levels 1 and 2 quality land presently in some form of grass cover; (b) reforest 10.61 km2 of level 1 land with shade coffee production on shallow soils; (c) evaluate the feasibility of intensifying land use on 30.93 km2 of forested level 3 land, and deintensifying land use on 37.50 km2 of level 3 crop land.

These management strategies recognize the risk of environmental deterioration as particularly high in the steeply sloping lands of Las Cuevas, termed "poor quality" land management zones (figure 4). They highlight, too, the underutilized agricultural potential in selected "good and high quality" areas (figure 5). The results recommend more detailed evaluation of these "good to high" potential areas where intensive farming could be practiced if appropriate technologies are adopted. The implementation of such strategies in the level to rolling upland areas of good to high potential productivity could establish a new, profitable intensive farming system in the region with a notable reduction in environmental stress on the adjacent steeplands.

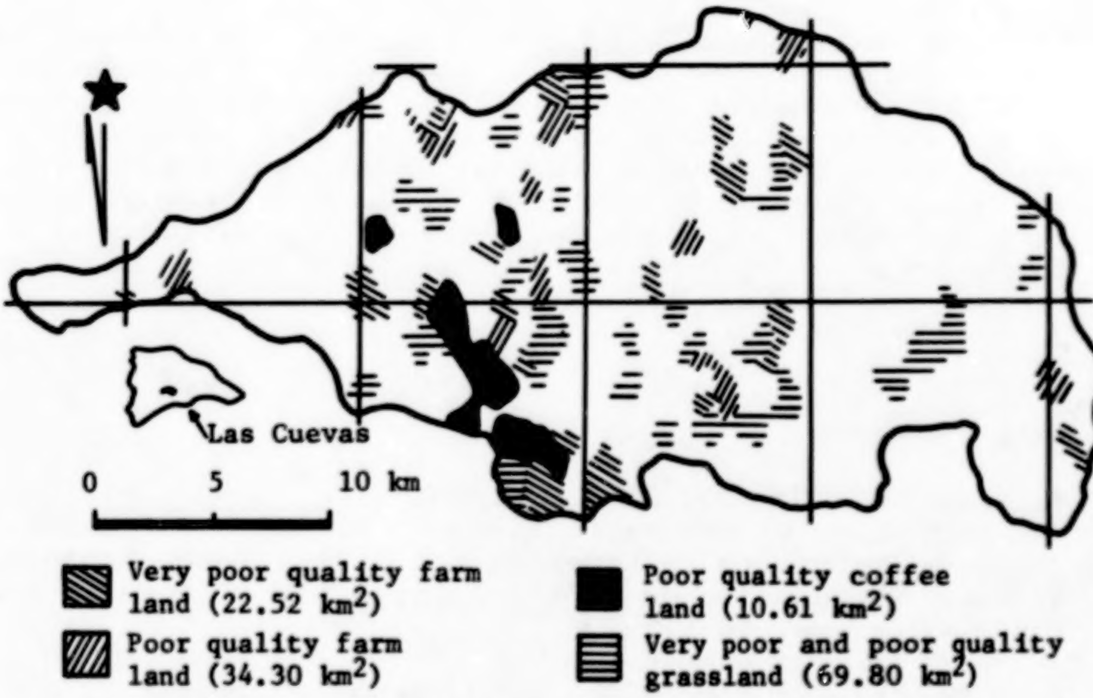

Figure 4. Poor quality land management zones.

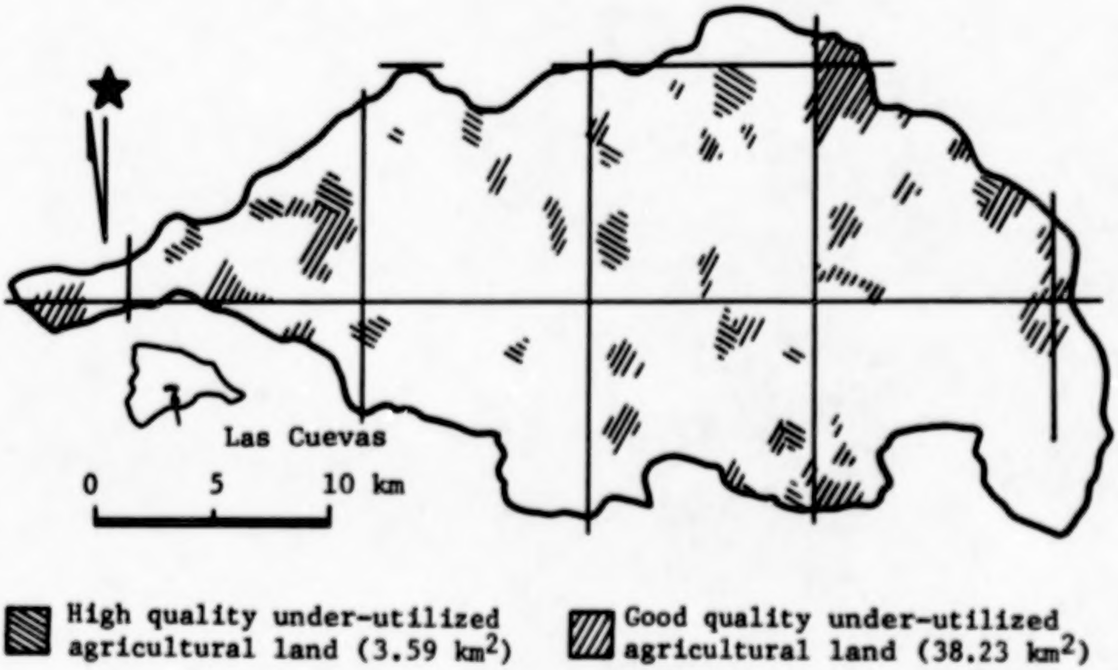

Figure 5. Good and high quality land management zones.

The authors believe that the procedure outlined above is a useful way of collecting, interpreting, and integrating spatial information on land quality and land use for development planning purposes. Detailed field inventory in inaccessible tropical steeplands is costly; it may be concentrated in key areas previously identified by field sampling, air photo interpretation, and computer cartography, allied with the computation of appropriate indices of change in environmental stress and land use/land quality compatibility.

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APPROPRIATE USES OF TOPOLOGY IN GEOGRAPHIC INFORMATION MANAGEMENT SYSTEMS

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ABSTRACT

Functionality and performance of Georgraphic Information Systems are best when designed and implemented with consideration of the user's applications. Appropriate applications for the topologic model and the merits of multifarious systems which allow creation of topology as needed are discussed. Benefits and drawbacks of topological and geo-relational data structures are outlined. GIS applications are presented with discussions of appropriate implementations of topologic data structures.

INTRODUCTION

Geographic Information Systems are implemented in a wide variety of applications and consequently should be flexible in design to exploit differing and dynamic requirements. The design of the geographic data base greatly effects the efficiency and effectiveness of systems. Performance is best when systems are designed and implemented with consideration of the user's applications. System solutions should take advantage of many technologies and capabilities, old and new -- the appropriate mix of capabilities is dependent on the applications.

Much emphasis is placed on the virtues of topologic data structures for mapping. Topology, often touted as the sole appropriate data base structure for mapping, is one of many capabilities available to system users. Indeed, some applications benefit from the topologic model, however, there are many applications for which other solutions are optimal. Systems which rely on only a topologic structure for mapping focus mainly on data analysis whereas systems using a geo-relational data structure are designed to address the breadth of needs in the mapping applications world.

This paper discusses the appropriate applications for the topologic model and the merits of multifarious systems which allow the user to create topology as needed to perform certain analyses. These systems maintain a geo-relational data base which allows great overall flexibility for geographic data input, analysis, retrieval and output. Mapping applications are presented with discussions of appropriate implementation of topologic data structures. Future system solutions are proposed for integrating capabilities of topologic and geo-relational systems.

DEFINITIONS

Geographic Information System (GIS)

The broadest definition of a GIS is a system for input, management, manipulation, analysis and output of spatially referenced data. The market defines GIS functionality in relation to other systems, such as AM/FM. In this view the emphasis of a GIS is transformation, analysis and geographic process modeling. GIS commonly rely on a specialized data structure called topology to perform spatial analyses of map coverages. A GIS can generate statistics, combine multiple data layers, and integrate data layers mathematically.

Geo-relational Data Structure

A data base structure designed for input, maintenance, storage and output of data for large geographic areas. The continuous or seamless map concept is facilitated by this structure. The structure is generic in nature, in that various types of data may be specified, precision may be defined appropriately by data type. Data is stored efficiently and in compact form to allow rapid search and display of data regardless of data base size.

Automated Mapping/Facilities Management (AM/FM)

An application of a geographic data management system in which facilities network models are integrated with the geographic data base. Includes tools for creating, maintaining and analyzing these models. AM/FM combines automated maping and data base management technology with the ability to search for records based on spatial location.

Mapping Information Management System (MIMS)

MIMS systems integrates the capabilities of both the GIS and AM/FM applications. MIMS allow flexibility of data base design beyond that offered by GIS or AM/FM systems alone.

GIS REALITIES

The world of GIS is one of certain realities. These realities greatly influence the growth and development of existing and future systems.

GIS systems are typically used in a wide variety of applications. These applications require various levels of system functionality and capability. Additionally, various data sources are required to serve each application.

User Requirements

User requirements are differing and dynamic in typical GIS environments. These shifting priorities and product needs result in the need for a robust GIS which can stretch to fulfill the requirements.

User Sophistication and Interest

Users of GIS systems are diverse in their level of computer ability, map understanding, and applications expertise. Some users want to write custom programs for their application, other users want to push a button and get output in map or report form. These various levels of user sophistication and interest indicate the system must provide multiple levels of user interfaces and access routines.

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Performance Requirements

Many users require minimal performance requirements for analysis, display, retrieval and plotting of information in a GIS. Every user wants results as quickly as possible; therefore, systems must continually evolve to meet the user demands.

Data Integrity

Integrity of data used in a GIS is crucial. The geographic data base comprises a primary asset of many organizations. Important decisions are made in reference to data in GIS systems. Related issues are data accuracy and precision. Data sources vary in accuracy and precision and the GIS must allow and account for those variances.

THE GEOGRAPHY OF APPLICATIONS

Landscape Variation

The nature of our landscape and people's impact on that landscape are illustrated in repeating patterns of urban, suburban, and rural environments across this and other countries. Most GIS systems reside in urban areas because it is there where the greatest needs exist for mapping and spatial analysis. The management of growth in urban areas has a strong element of geography. The Mapping Information Management System is a tool for aiding in decision-making regarding many aspects of growth -- facilities placement, zoning, property division and record maintenance, road planning and construction, district and boundary redrawing, tax reassessment, site selection, and building permit tracking.

This geography is typically categorized into three main zones -- the urban core, the suburban fringe, and the outlying rural areas. These areas grow differently; activities and applications also differ across these zones. In the urban core the main applications for a geographic information management system are for facilities management, tax assessment, record keeping, and transportation analysis. Little planning typically occurs in the urban core as it is usually fully developed.

Moving out from the urban core, one reaches the suburban fringe. GIS users there are concerned with facilities planning, development management, zoning and road maintenance. Rural area applications are highway maintenance, property record keeping, long-term development planning, agriculture, forestry, and land lease management.

Data Structures for Applications

As the applications in these three zones vary, so do the appropriate data structures to serve them. A geo-relational structure is appropriate for the urban core. In the suburban fringe, the emphasis is on the geo-relational structure with some use of the topologic structure. In rural areas, the analysis needs indicate topology to be the primary structure with less use of the geo-relational structure.

Solutions

Optimal solutions to these GIS realities are systems which are designed for applications, use technology appropriate to the application and user, require relatively little maintenance of the data base, allow flexibility of data base design, and present the ability to customize applications.

WHERE TO USE GIS

Benefits of Topology

The topologic model is a framework within which certain GIS analysis is possible. The topologic relationships of the data elements allow processing of areal or polygonal data. Typical functions include polygon overlay, point-in-polygon analysis, polygon aggregation and disaggregation. These functions are useful for applications such as site selection, environmental assessment, incidence mapping, zoning, and network analysis. Applications in which areas or polygons are the data elements to manipulate and analyze are well served by the topologic model.

The Price of Topology

A topologic data base is only useful if it is mathematically correct. The complex inter-relationships of spatial elements must be created and maintained with editing. Storage requirements are often larger than for the non-topologic data base. Systems which require topology -- whether or not the user requires it -- forces users to carry the extra overhead associated with topologic elements. Additionally, because of the complex processing associated with topologic data, routines are commonly batch-oriented rather than interactive -- a disadvantage in today's demanding user environment. Lastly, topologic data is costly to digitize and edit because the spatial relationships must be maintained. In summary, the price of topology is a more fragile, demanding, and slower performing capability than the non-topologic data elements.

Applications - Where Topology is Necessary

The wide range of applications in mapping and GIS present a wide range of possible system requirements. From demographic analysis to AM/FM, applications are varied and have differing requirements. Applications may be grouped by industry -- Natural Resources, Municipal, Utilities, Transportation, Telephone - or by function - Planning, Engineering, Facilities Management, Automated Mapping, Routing, Base Mapping. Industry groups and functions overlap -- many of the functions performed in a municipality are also performed in a utility company. However, all members of a particular industry do not necessarily perform the same functions (Figure 1).

Systems have evolved to serve particular functions rather than industries. These functions are optimized in certain types of systems. Analysis-oriented systems are designed to perform planning and analysis functions while AM/FM systems have attracted the geographic records maintenance and engineering functions.

Unfortunately, the technology historically did not always parallel the applications. AM/FM systems typically had highly effective data entry and editing capabilities which are useful for many planning applications which also use toplogic processing. Topological analysis systems had excellent geographic and analysis capabilities for areal data. Users wanting both had to purchas two systems or Force fit applications on one system.

Today, the most efficient and effective solution is the GIS which has the flexibility to allow topologic and non-topologic data structures integrated in one system. These newer systems give users a choice when building data bases for particular applications. Topologic processing is an analysis tool, the results of which are stored in the geographic data base. With this flexibility there is no force-fit, i.e., the data structure fits the application.

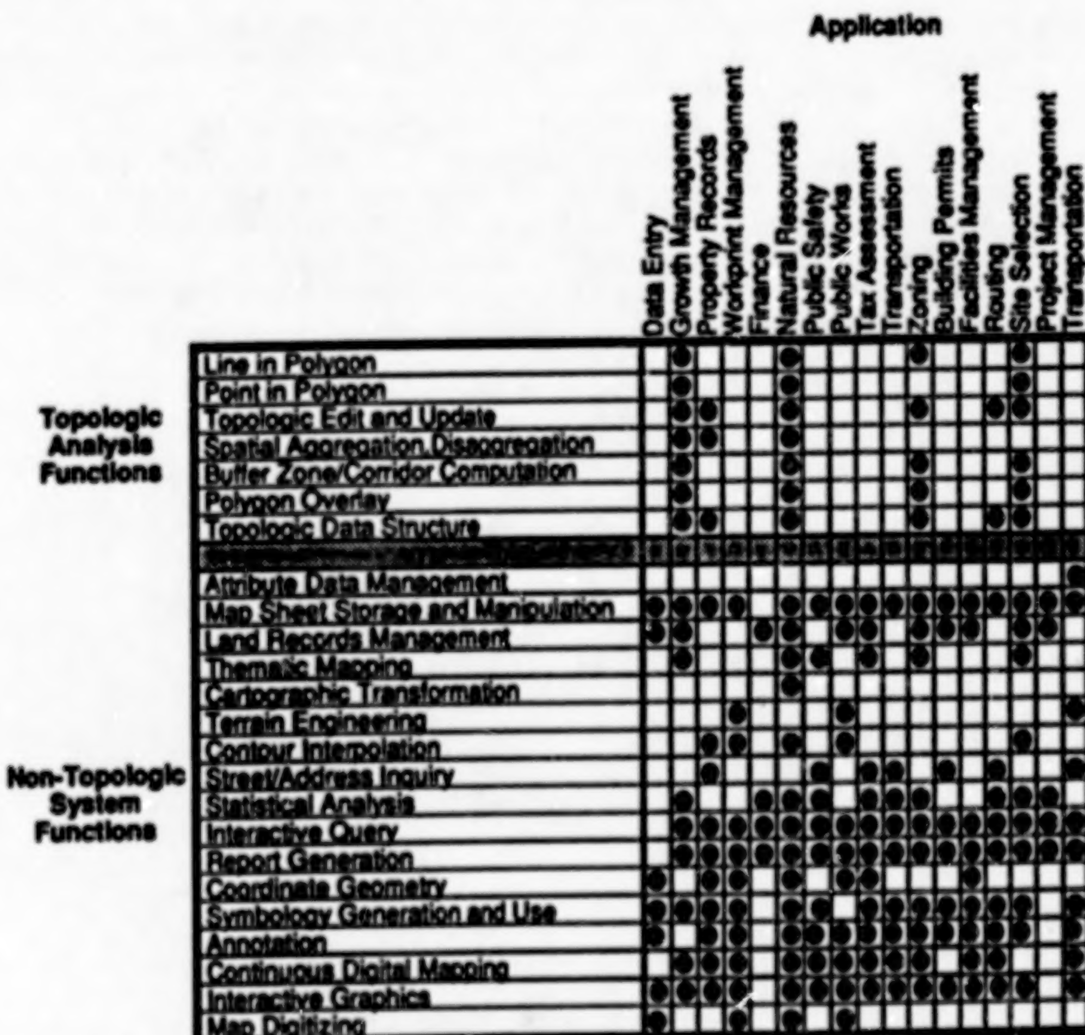

FIGURE 1.
APPLICATIONS OF LIS FUNCTIONS

CONCLUSIONS

GIS solutions are applications driven. Topology is appropriate for some applications, but because it carries a significant price tag, its implications as a sole solution should be questioned. Pure topologic data base structures are theoretically comfortable, however, practical consideration indicates a more powerful and cost-effective solution in systems which allow both topologic and non-topologic data creation, revision, manipulation, storage and retrieval. Multifarious systems allow the flexibility to mix applications -- those which require topology and those which do not. Additionally, many applications require partial topologic analysis, i.e., only a portion of the problem is solved using topologic analysis functions. The kep point is that your choice is application-driven and most users require flexibility to build many different applications, some of which are more efficient in non-topologic environments.

Certain types of systems have thrived in either the Planning/Natural Resources market or the AM/FM market. Systems with topologic-only data structures address a relatively narrow range of applications in the GIS/LIS and AM/FM markets. AM/FM systems without the capability to process topologic data address other application requirements. Few systems have integrated capabilities to be useful for all GIS and AM/FM Markets. AM/FM systems without the capability to process topologic data address other application requirements. Few systems have integrated capabilities to be useful for all GIS and AM/FM applications. Systems which allow creation, manipulation and storage of both topologic and other geographic data structures allow multiple applications to take advantages of a single mapping geographic information data base. Flexibility is the key to meeting the challenges of today's GIS applications world.

COMPUTERIZED INFRASTRUCTURE MANAGEMENT IN SAINT PAUL

Richard A. Person

Manager of Infrastructure Management Services

Saint Paul Department of Public Works

ABSTRACT

The City of Saint Paul is developing a comprehensive infrastructure management system including facility inventories, condition assessments, and maintenance management systems. The heart of the system is a geographic database derived from the US Census Bureau DIME File. The system is being integrated with the county cadastral database for computer assisted mapping.

1. INTRODUCTION: The 'Infrastructure Crisis'

National attention has focused in recent years on the potentially serious decline of our public infrastructure facilities: roads and bridges, sewer and water systems, and others. These facilities serve our most basic public purposes: streets and highways allow commerce and movement of people; sewers protect health; water distribution provides clean water. They often are part of larger systems such as county, state, and federal highways or regional sewer systems.

The Saint Paul 'Shareholders Report' places the total value of our Public Works assets at $1.6 billion. This figure includes only the street system and the sewer collection system, and only for the City of Saint Paul. It does not include the water distribution system, water and sewage treatment facilities, or any other utilities, the total value of which is many times $1.6 billion.

The foundations of national concern about infrastructure are varied. The aging of the early 20th Century and post-war surge in public works construction, particularly in the northern tier of the country, has inevitabilly led to a replacement bulge. Most cities have become victims of a coincidence of replacement cycles.

During the deep recessionary period brought on by the energy crisis in the 1970's, local officials consciously decided they must postpone or defer maintenance in order to maintain police and fire, and human services. Pat Choate's America in Ruins documented a 25 percent drop in infrastructure spending since 1972, from 5 percent of GNP to 0.7 percent of GNP today.

But it is becoming increasingly clear that deferring maintenance only leads to a buildup in future maintenance requirements and costs, reduces service quality and increases service interruptions, depending on the rate of deterioration of individual facilities and on how long maintenance has been deferred.

Estimates range from $200 billion to Choate's widely-quoted $3 trillion or $900 per family to repair the backlog of public works facilities in poor condition. Even the lower estimates are far in excess of available resources under even the most optimistic projections of new revenue. According to the National League of Cities, this backlog would require a 40 percent increase in local taxes.

1.1 Infrastructure Management Process

A carefully conceived infrastructure management process will result in the consistent programming of a city's current and future capital infrastructure needs. This process involves:

- @ Assessment of the physical characteristics and condition of the city's infrastructure.

- @ For those infrastructure items with problems, the analysis of options such as: continue maintenance with emergency repairs, overhaul/rehabilitation, or replacement. The analysis includes comparison of costs, service level impacts, the uncertainties and risks associated with each option, and financing alternatives for each.

- @ Ranking, prioritizing, selection and funding of specific infrastructure improvement projects.

Stages of the infrastructure management process are shown in Figure 1. Saint Paul Public Works is phasing in computerized infrastructure management systems over several years, with the highest priority applications implemented first. Developing a street segment oriented facility management system that can be enhanced to include detailed engineering mapping capabilities will assure that later applications can be added which will function properly within the system.

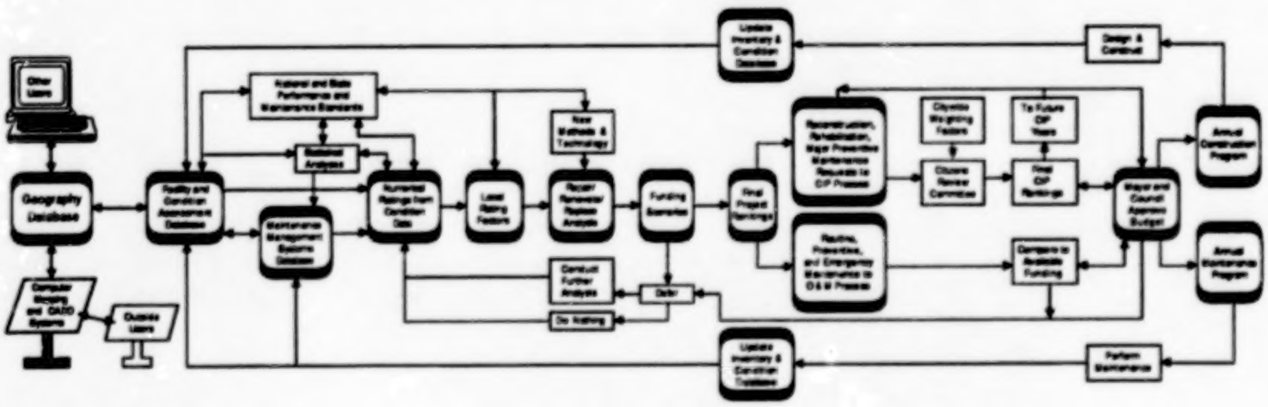

Figure 1. Infrastructure Management Process

2. SYSTEM COMPONENTS

A public works infrastructure management system requires a relatively high performance computer system, with enough disk capacity and processing speed to handle complex queries or data manipulations for large databases, including digital graphics.

Fortunately, the relatively inexpensive advancements in computer technology are making this type of sophisticated computer application practical for smaller and smaller local governments. A recent Government Data Systems survey reported that 99 percent of local governments with greater than 10,000 population are using computers. Fifty percent have multiple computer installations, commonly in police, public works, and utilities departments. Thirty percent of employees have workstation access, and there is currently one microcomputer per 20 employees.

Saint Paul is developing a comprehensive infrastructure management system for the city's major public works facilities: streets, sewer and water mains, lighting poles and traffic signs, sidewalks, and bridges. The system includes detailed facility inventories and condition assessments, maintenance management systems, management report generation for operations monitoring and capital improvement planning, and will include computer aided mapping/graphics capabilities.

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Saint Paul Public Works installed its first computer in 1979. From that small beginning, Public Works Computer Services is today an advanced, distributed processing UNIX configuration with 60 interactive terminals accessing a Pyramid 98x Superminicomputer and a Britton-Lee Intelligent Database Machine, various printers, three TI/AutoCad and three Compaq 386/AutoCad workstations for computer-aided drafting and design. The Department also has 50 microcomputers including 45 Macintoshes, several of which have direct access to the central computers. Most of the micros are used for word processing and accounting. The PWCS computer configuration is depicted in Figure 2.

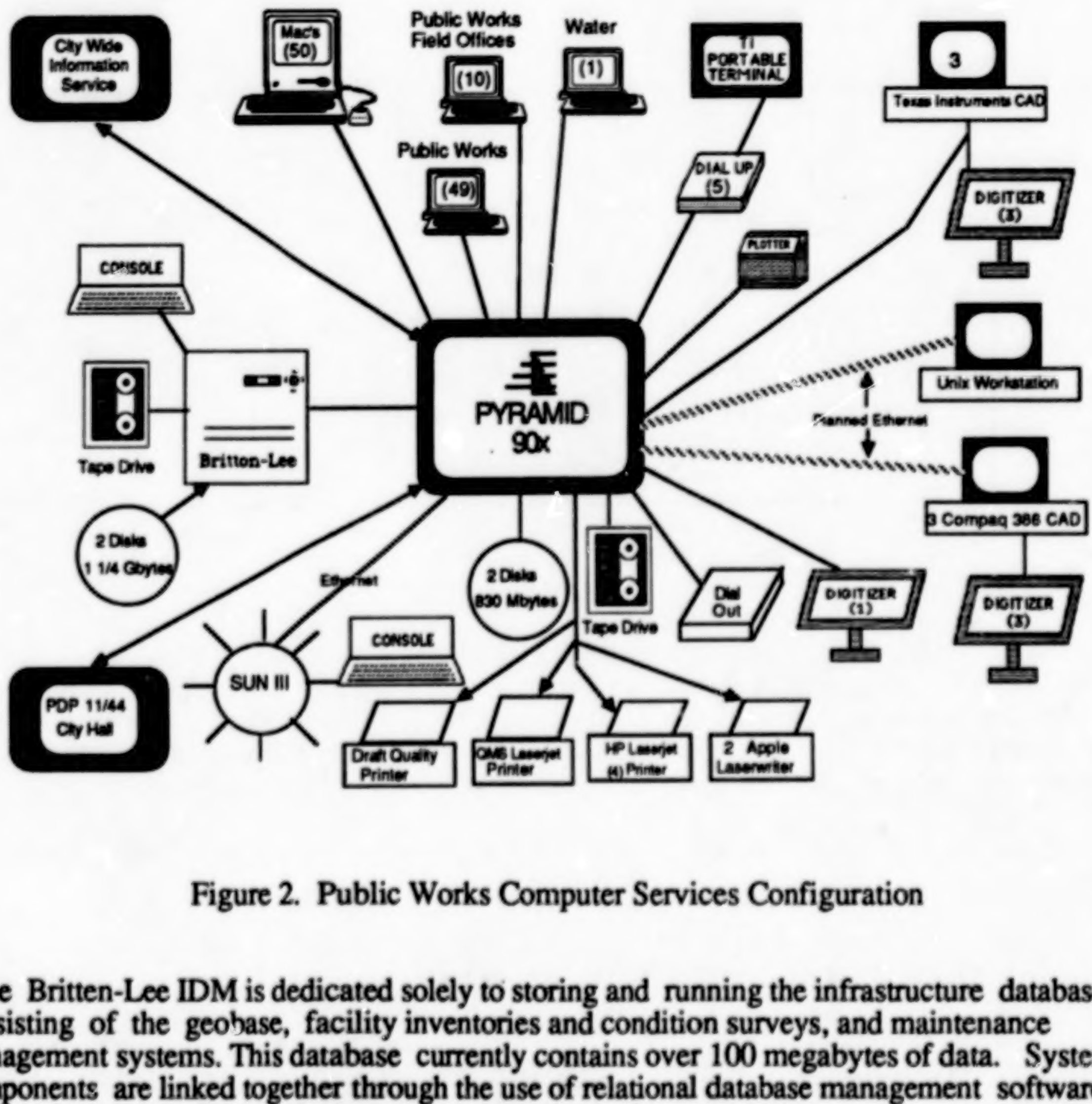

Figure 2. Public Works Computer Services Configuration

The Britten-Lee IDM is dedicated solely to storing and running the infrastructure database, consisting of the geobase, facility inventories and condition surveys, and maintenance management systems. This database currently contains over 100 megabytes of data. System components are linked together through the use of relational database management software and the consistent use of 'geocodes' among and between the components.

<u>Geographic database</u>. A geographic database contains the complete geography of a city in computerized form describing the city's street segments and nonstreet features such as railroads and water bodies. The Saint Paul 'geobase' is derived from the U.S. Census Bureau GBF/DIME (Dual Independent Map Encoding) File. The DIME currently exists for every major metropolitan area and after 1990 the new TIGER file will be available nationwide. Many municipal geoprocessing needs can be satisfied immediately with this very cost effective (free) geographic database. Figure 3 shows a typical DIME street segment layout.

Figure 3. Typical DIME Street Segment

Geocodes established in the geobase structure include: City Council Ward, Planning District, Ramsey County and Water Utility Street Codes, Map Number, Address Range, Police Zone, Fire District, School Attendance District, Zip Code, and State Plane Coordinates. Public Works attempted to include every geocode that would link the geobase with computerized records kept by potential system users throughout the Saint Paul city government.

The geobase is the structure on which the rest of the infrastructure management system is built.

2.1 Facility Inventory and Condition Data Sources

Public works departments keep extensive paper records describing their capital facilities. These records vary by facility type, but their basic organization is similar. Each public works operation:

@ Maintains detailed construction plans and maps which contain basic engineering and locational information.

@ Conducts facility condition assessments, some more formal than others.

@ Follows facility maintenance schedules.

@ Uses a work or job order to inform crews of the maintenance work required, and to record actual work performed.

@ Logs completed maintenance work by location.

The engineering, condition assessments and scheduled maintenance information for each public works facility are the heart of the infrastructure management process.

Facility Inventories. Basic elements of a facility inventory include unit (street, main segment, bridge, pole, sign, etc.), location, dimensions, material/construction, value/cost, maintenance responsibility, funding eligibility/sources, and others.

The inventories relate facility type and engineering data to the proper street segment in the geobase and location within the street. St. Paul Public Works has completed inventories of six different facility types -- streets, sewer mains, water mains, traffic signs and lighting poles, and sidewalks. A seventh inventory of all contracts the city has had since the mid 1800's provides a history of work performed in or under each street segment.

The inventories were compiled using a two step process. During the design phase, the project manager and consultant met individually with staff from each operating division. Each group decided what information about their facilities should be compiled and where the information was found, either in existing records such as maps and reports or as new data gathered in the field. Then a pilot inventory for one small area of the city was conducted to aide in refining inventory procedures. Finally a manual was prepared for each inventory to guide coders, and the necessary file(s) set up in the computer system for entering the data.

Next, interns and temporary workers compiled and entered the data into the computer by street segment for each facility. Some inventories required a two step process of coding paper forms first, then entering the data. The seven current inventories are described below.

@ The Street Inventory includes location (quarter section), street material type, aid category, plow class, assessment class, distress points condition rating, right-of-way and roadway width, street length, and traffic count for every street in the city.

@ The Sewer Main Inventory contains the map number, sewer type, construction type (combined or separate), maintenance schedule, drainage district, length, direction of flow, slope, ownership, backups and complaints for each sewer segment. This inventory is currently coded by street segment. We are in the process of recoding to a manhole-to-manhole, or sewer main segment basis by digitizing manhole locations from original plan sheets.

@ Light Pole Inventory information includes pole location, style, color, paint condition, structural defects, traffic signal on light pole, arm length, arm type, arm mounting angle, base type, fixture style, and other pole uses.

@ The Sign Inventory contains sign location, message code, sign material, legend color, background color, width, height, sign face reflectivity, and mounting type.

@ The Water Main Inventory is very similar to the sewer inventory: map number, location, segment number, diameter, length, offset from odd or even property line, year constructed, material type, temporary or abandoned main, and main breaks.

@ Sidewalk Inventory information contains location, construction type, width, property use, description of faults (differential joints, cracking, scaling, asphalt patching, sunken walk, and irregular grade), and comments. The precise location of all sidewalks and curbing in the City of St. Paul is being stereodigitized from aerial photos during with the Ramsey County land base production.

@ The Contract Inventory data includes location, distance and direction from intersection, three-letter code descriptions of work completed, year, contract number, and comments.

@ Boulevard Trees. The Saint Paul Parks and Recreation inventory of 80,000 city-owned trees in the public right-of-way has been integrated into the Public Works system. The precise location of the trees is being digitized along with sidewalks and curbing.

@ Bridges. Public Works conducts annual sufficiency ratings on every bridge in St. Paul, then works with Minnesota DOT on repair/renovation prioritization. MnDOT currently maintains the bridge inventory statewide. This inventory will be integrated into the system at a later date.

Facility condition assessments. Condition assessment is the process of measuring the frequency and severity of facility problems, using specific, clearly defined indicators which limit subjective judgement and ensure consistency. The basic elements of condition assessments are safety and structural integrity, and may include capacity/level of service indicators (e.g. number of vehicles per hour, or number of gallons per minute at a certain pressure), and indicators of the quality and criticality of service (e.g. number of people/businesses affected, extent of inconvenience, etc.).

Age is widely used as a condition indicator even though uniformly accepted estimates of 'average' facility lifetimes are difficult to define. Factors such as initial design, quality of materials and construction, use of a facility and the conditions it is exposed to, and the quality and frequency of maintenance are often more important than chronological age. Many facilities need replacement before their theoretical useful life is reached, but many last longer, particularly those maintained properly.

Condition surveys most commonly involve visual inspections of facilities by trained observers using specifically designed rating forms and procedures. Also, the public often makes observations of facility condition in the form of complaints or reports of various facility failures called into operating agencies. Finally, maintenance crews observe facility condition as part of their routine operations and inform their supervisors or refer information to other units of the organization.

Of increasing importance are numerous types of electro-mechanical devices now used to enhance our ability to survey the condition of pavements, sewers and water mains. And increasingly in the future, the use of sensors will be integrated extensively into the assessment process with artificial intelligence, to refine failure prediction and trigger maintenance activities.

Street Condition Rating Procedures. The basis of pavement management is the ability to track pavement deterioration and diagnose the cause. Visual observation procedures include distress rating systems such as the Asphalt Institute Pavement Rating System for Low-Volume Asphalt Roads, and the U.S. Department of Transportation distress rating system, which is used by Saint Paul Public Works. The Saint Paul survey is conducted every other year on all arterials and on residential streets according to special needs. Traffic counts are taken every third year.

Sewer Main Condition Rating Procedures. The sewer inventory contains information on the location of sewer main breaks per segment. The inventory also includes extensive data from a citywide postcard survey of basement sewer backups and street flooding. We are working on integrating sewer main TV data and pressure/capacity measurements where available.

Television inspection is the most widely-used and effective technique for documenting the quantity, location, and severity of structural integrity problems; root intrusion, grease, and sediment presence; infiltration into mains and laterals; protruding laterals and defective lateral

connections; offset joints; dips in pipeline, horizontal or vertical deflections; and cracking. One crew can televise about 40 to 50 miles of sewer main per year. At this rate, it will take 15 to 20 years to complete televizing the system in Saint Paul. Public Works also undertakes periodic visual inspection of large mains, manholes, and pump stations.

Water Main Condition Assessment. The Saint Paul Water Utility has kept detailed records of all water main breaks from 1956 to the present. This data has been entered into the water main inventory. The Water Utility conducts system audits of unaccounted-for-water, including sonic leak detection surveys, and meter replacement programs. We are working on integrating existing inventories of hydrants, valves and service connections into the infrastructure database.

2.2 Maintenance Management Systems

One major use of the inventories and geobase is automation of maintenance work order processing. These records contain detailed information about frequency and severity of facility problems, often including labor and materials used to correct them. Properly analyzed, work orders can provide data on the costs of maintenance, pinpointing locations in the system experiencing frequent problems and high maintenance costs.

Cost data in turn can be used to evaluate the economics of continued repair versus rehabilitation or replacement of individual facilities. Other important features of maintenance management systems are constant updating of condition information in the facility inventories, and creation of a maintenance history for each individual facility. The Maintenance Management Process is shown in Figure 4.

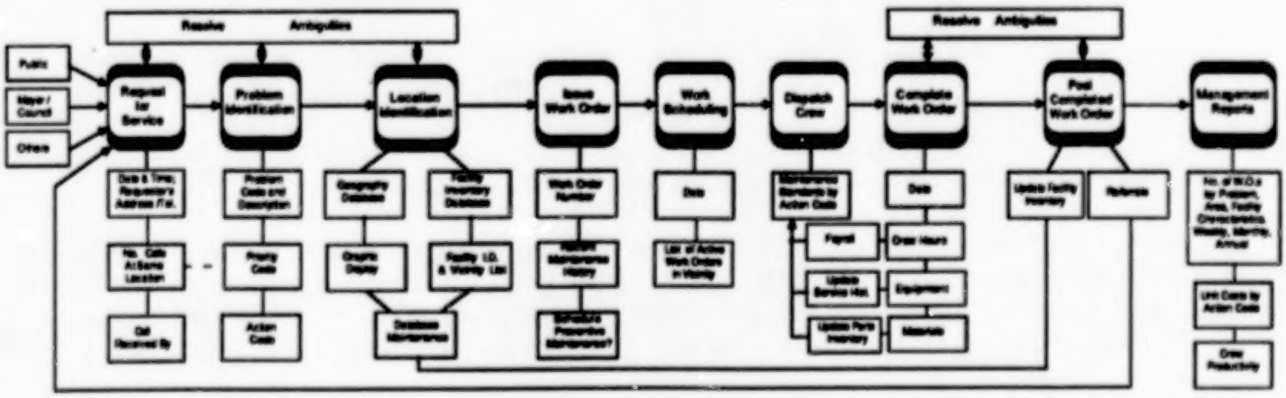

Figure 4. Maintenance Management Process

Public Works is developing a pilot system for Traffic Lighting Operations. The light pole inventory provides the basic locational and descriptive data. The rest of the data will be built up over time by entering the maintenance actions performed from completed work orders.

@ Management reports -- Automated processing should eliminate 'lost' work orders and improve crew scheduling efficiency. Supervisors will be able to monitor work backlog daily and weekly, readjusting crew activities for maximum responsiveness. Over time, supervisors and managers can develop and refine crew productivity standards, and compile monthly and annual reports the of materials, labor, and equipment used in each maintenance activity.

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Managers can experiment with different levels of maintenance to determine if the level can be reduced without negative impacts, or should be increased to reduce deterioration rate. Maintenance management data will make comparisons between actual and planned performance possible, resulting in uniform levels of maintenance service applied consistently citywide, but with regard for differing locational, material, or other variations in individual facilites.

@ Inventory updating -- Work order data will constantly update the facility inventories with information about scheduled and extraordinary maintenance performed on each individual light pole, sewer main, street segment, sign, etc; and any changes in location or physical characteristics.

@ Maintenance history -- A history of maintenance actions and cost will be built over time on each individual facility, providing managers the basis for analyzing chronic maintenance problems and refining budgets and schedules for preventive maintenance activities, major renovation, or replacement of facilities.

Thresholds can be established in the database for identifying individual facilities with cumulative maintenance expenditures exceeding the average by a specified amount during a specified time period. Also, the database creates a complete audit trail for legal investigations resulting from damage claims.

2.3 Computer Aided Mapping

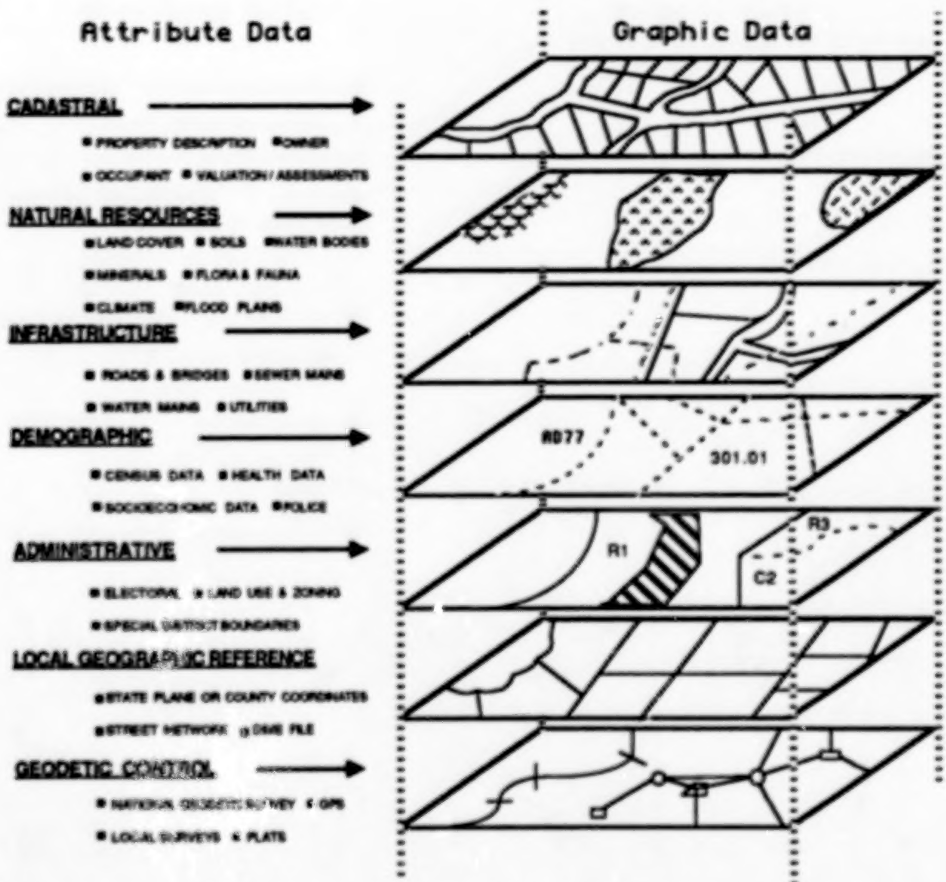
The node (street intersection) coordinate values in the geobase make it possible to generate maps depicting the Saint Paul street network. The Geobase Mapping System can currently generate maps showing street center lines and non-street features, e.g. railroads, for any geographic area defined by geocodes established in the geobase. It is being used to identify geobase inconsistencies and inventory coding errors for correction.

A significant problem inherent in the Geobase Mapping System is the ± 3 percent accuracy of node coordinates derived from the DIME File, due to poor source materials used by the Census Bureau and digitizing error. The system is adequate for 'geographic' mapping applications which do not require great accuracy, but not for cartographic or engineering applications.

@ Public Works has significantly improved the accuracy of the node coordinates, using COGO to calculate values and/or digitizing points off of quarter section maps.

@ Ramsey County began a four year effort in 1986 to complete a multipurpose cadastral mapping database countywide. Basic geodedic control has been provided to the database using the Global Positioning Satellite system. The county is using an integrated geoprocessing/facilities management/computer aided mapping/computer aided drafting and design package developed by Hennepin County called ULTIMAP. St. Paul Public Works will integrate the Infrastructure Management System with the Ramsey County computerized land base.

Also, the utility companies and others can create and maintain their own facility [illegible] to the computerized county maps, using the system for facility management and to replace manual mapping systems. System users will eventually be able to exchange facility-related data under the auspices of a regional mapping consortium now under discussion, leading ultimately to a regional 'one call system' for buried infrastructure. The concept of an Integrated Geographic Database is shown in Figure 5.



Source: Adapted from Wisconsin Land Records Committee, <u>Summary Report</u> October, 1986.

Figure 5. Integrated Geographic Database Structure

<u>Display Features</u>. The mapping system will be able to produce maps at any scale or size, and display all cartographic elements currently on the Public Works standard maps. Facility display features will include:

@ Either their relative location in the right-of-way or easement according to inventory coding, or their precise location digitized from plan sheets or other sources.

@ Their characteristics, by use of annotation or symbols, from the facility inventories.

Data will be retrieved by any combination of street segments, quarter section, census tract, planning district, ward, zip code, etc.; or by areas specified by a system user, such as all features within a 1,000 foot radius of a given intersection. The mapping system will have application interfaces for:

@ Graphic display within the Maintenance Management Systems.

@ Background drawings for computer aided design and drafting or site planning, such as the St. Paul Public Works Combined Sewer Separation and street reconstruction program.

@ Socio-economic, land use, zoning, and other special purpose applications through a citywide geographic information system.

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2.4 Management Decision Making Aids

The Public Works divisions are using the inventory and condition data, plus divisional weighting factors, as a starting point for making decisions about which facilities to maintain or replace, and whether individual facilities with lower or marginal numerical ratings should be assigned higher priority or vice versa.

For example, the sample street inventory printout in Figure 6 lists several street segments along Como Avenue with 1982, 1984, and 1986 distress points. Traffic counts for each segment are an additional analysis parameter. Street maintenance uses this report to prioritize street paving and maintenance projects.

Distress Points	Year	Matl Type	Aid Cat	Asmt Class	Plow Clas	Odd Sdwk	Even Sdwk	ROW Width	Road Width	Leng	Traf Count	Year
COMO		ALBERT		PASCAL			028743					
10	1982	CB	MSA	2	SE	MT	M	100	50	0	8.0	82
20	1984											
30	1986										7.5	85
COMO		ARGYLE		CHATSWORTH			028735					
26	1982	O	CITY	2	SE	M	M	40	0	0	3.0	82
48	1984											
52	1986											
COMO		ARONA		SNELLING AV*			028746					
10	1982	CB	MSA	2	SE	M	M	100	50	0	7.9	82
38	1984											
45	1986										7.5	85
COMO		ATWATER		MACKUBIN			028720					
35	1982	CB	MSA	2	SE	MT	M	100	58	0	7.0	82
58	1984											
0	1986											
											8.6	86

Figure 6. Sample Street Inventory Printout

Potential sidewalk replacement projects are automatically ranked by the computer, including an estimated cost calculated for each. Sidewalk maintenance has used the rankings extensively to program limited panel replacement funds. They may defer non-critical projects that need further detailed analysis to the next year.

The infrastructure management program is a complex, long-term effort. It will continue to take hard work and cooperation. We have been able to accomplish much without a large staff or funding. Our success thus far is attributable to political support from a farsighted Mayor and City Council, and to the strong commitment of the Public Works Director and division managers.

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A GIS FOR LOCAL HEALTH SERVICES PLANNING

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ABSTRACT

Because an increasing percentage of the United States' gross national product is being devoted to health care provision, more attention has been given to the containment of health care expenditures and to effective methods for health services planning. To this end, local health services planning districts have been established within individual states. This paper proposes a design for a geographic information system (GIS) for local health services planning. Local health agencies have traditionally been responsible for maintaining and analyzing data on vital statistics, environmental risks, and health care delivery in their areas.

The use of automated management information systems by hospitals and other medical care providers is well-established. And, the methods of computer-assisted cartography have been applied to describing geographical patterns of disease. This experience has contributed to identification of the dimensionality of key geographic features of the health services system. However, three factors will affect the ability of local and state government to incorporate this experience into a functioning information system for local health planning: adequacy of staffing, opportunities for interagency exchange of health, medical, and geographic information, and accessibility of health and medical data at a meaningful level of aggregation. These requirements will be examined with reference to the health service system of the State of Connecticut.

1. INTRODUCTION

The development of GIS technology over the last 25 years, though remarkable, has been limited to only a few areas of application (Tomlinson and Boyle, 1981). Resource management, forestry, and land registration have made particular use of GIS. As GIS software and hardware have developed and a number of standard products are available, new areas of application including marketing and retail trade are emerging. Another major sector of the economy apparently ripe for the development of GIS is the health and medical care sector.

Because an increasing percentage of the United States' gross national product is being devoted to health care provision, more attention has been given to the containment of health care expenditures and to effective methods for health services planning (Jonas, 1986). In addition, the last decade has witnessed tremendous concentration in the medical care industry in hospital chains, physician group practices, and medical management firms whose operations are coordinated over increasingly large geographic areas. Local health services planning districts have been established within individual states to facilitate and regulate medical care provision. This paper proposes a design for a geographic information system (GIS) for local health services planning. Local health agencies have traditionally been responsible for maintaining and analyzing data on vital statistics, environmental risks, and health care delivery in their areas. The dismantling of Health Systems Agencies created under the Health Resources Planning and Development Act has placed an even greater burden on local health agencies.

Fortunately, the search for a GIS for local health services planning is not without guideposts. Medical care providers have an established history of automated management information system use. And, the methods of computer-assisted cartography have been applied to describing geographic patterns of disease. This experience has contributed to identification of the dimensionality of key geographic features of the health services system.

2. HEALTH INFORMATION SYSTEMS AND GRAPHIC DISPLAY

The application of computers to the preparation and display of health-related information began in the 1960s. Hospitals, as individual institutional providers, were the first to devise and implement automated management information systems, particularly in the United Kingdom where medical care provision was nationalized (McLachlan and Shegog, 1969). The primary purpose of these systems, however, was internal hospital management and computers supported basic billing and accounting functions in addition to medical records processing. For the administrative sector, the introduction of electronic data processing was relatively straightforward mirroring the developing and documented applications in commerce and industry (James, 1969). In the medical sector, the use of computers was extended into medical practice itself in computer-aided diagnosis, intensive care monitoring, and image processing by university teaching hospital staff who pioneered medical computing (Flowers, 1968).

At the same time, largely outside of mainstream medical care delivery, epidemiologists and social scientists began to apply the computer to the preparation of data for mapping and for constructing computer graphics (Armstrong, 1972). The output form of the earliest products was restricted by the capabilities of line printers. Computer

graphics were in some cases used for map compilation; working maps were prepared for later drafting. This approach was particularly taken in a number of disease atlas projects.

Some of the earliest uses of computer-assisted mapping for medical care planning occurred as part of the 1965 study of hospital utilization in Greater Los Angeles showing admissions by census tract (Drosness, Reed, and Lubin, 1965) and the 1968 study of hospital use in Chicago (Morrill and Earickson, 1968). The growth in medical care expenditures following the implementation of Medicare and Medicaid (Title XIX and Title XX of the Social Security Act) was followed by the enactment of the National Health Planning and Resources Development Act of 1974. This Act provided for the establishment of Health Systems Agencies to develop comprehensive health plans for regions and to review providers' capital expenditure proposals through a Certificate of Need process (Jonas, 1986).

Although the HSAs were expressly prohibited from collecting primary data, geographical analysis of secondary data on medical care utilization, population, and health status was an important part of the HSAs work. A number of these agencies developed automated systems for the graphic display of health and medical information to be used in the planning and regulatory processes (Bohland, Barb, Lundy, and Ashmore, 1979).

This experience has contributed to identification of the dimensionality of key geographic features in health and medical care systems. Point data record the locations of health care providers and users (Shannon, Spurlock, Gladin, and Skinner, 1975). Population and health status information are also point data although they are frequently aggregated by areal unit (Shiel and Wepfer, 1976). Spatial interaction between providers and users is linear data (Kane, 1975). Finally, environmental risk factors can be point or area entities depending on how localized the risk is (Boots, Getis, and Hagevik, 1972). The collection and analysis of health and medical information for local health services planning is guided by the functions of local health agencies which, unlike HSAs whose federal support was terminated during the budget cutbacks of the 1980s, both plan for and deliver health services.

3. FUNCTIONS AND DATA REQUIREMENTS OF LOCAL HEALTH AGENCIES

Local health services are defined as health services financed either totally or in part by a governmental unit smaller than the state. These services are organized in a variety of ways. In some states, a central agency locates and staffs satellite offices. In other places, services are provided through municipal or county health departments. In Connecticut, where more than 3.0 million reside in 169 towns, local health departments are supported by individual towns or groups of towns.

By regulation, local health departments supporting full-time directors are eligible for capitation payments and grants from the state. These

departments are required to perform a minimum of eight basic functions (Figure 1). Departments are permitted to provide some services through contracts with other organizations. In performing these functions, departments are involved in information processing, identification of health problems, and direct service provision. Local health departments supervised by full-time directors serve in 26 individual towns and 12 multi-town districts covering a total of 58 towns (Figure 2). In the remaining towns, local health services are supervised by part-time directors, generally private practitioners who are crisis-oriented in their responses to local health problems. In these departments, there is no opportunity for supporting a technical staff capable of managing a GIS.

Most departments serving larger towns have access to the computing resources of their local governments, though these vary widely and are generally in place to manage town finance and budgeting functions. The State provides a subsidy to departments with full-time directors to enable them to purchase time on a computer network tying health departments across the nation to the Centers for Disease Control and the Food and Drug Administration. This system is used primarily to dispatch information for recalls of contaminated products. Approximately half the full-time departments are tied to this network.

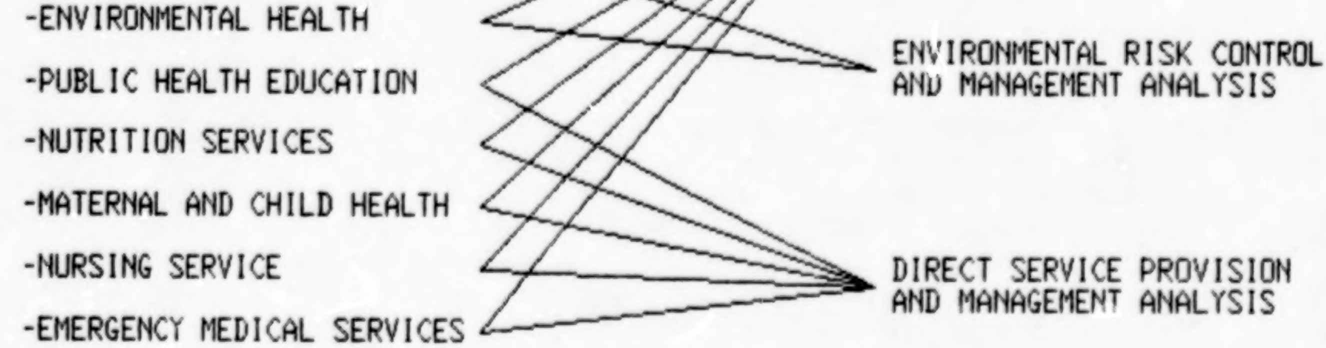

Figure 1. Functions of local health departments.

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Departments receiving grants from the State are required to file annual reports of grant expenditures and the outcomes of health activities supported by the grants. Local staff have expressed the need for more information to support local decisionmaking. In recent Annual Reports, information on natality, morbidity, and mortality for local needs assessment and programming, information related to environmental quality (new housing starts, water and sewage, private drinking water supplies, asbestos), and community health education needs were particularly mentioned as important issues in local public health.

4. SYSTEM PRINCIPLES AND DEVELOPMENT

An effective GIS must be able to provide the answers to a set of basic queries: 1) what is the value of attribute X at place Y; 2) where is object A; 3) where is A in relation to place B; 4) what objects are next to objects having a certain combination of attributes; and 5) what is the result of intersecting various types of spatial data. These questions are answered through specific system functions designed to facilitate information processing. In a general-purpose GIS, many functions involve pre-processing data to generate a final database. Most of these functions such as line generalization and projection change are only relevant in the initial compilation of data. They would not be necessary in a local health services planning sytem because the database is from secondary sources.

Low staff support in local health departments precludes agencies from compiling their own geographic and the bulk of their thematic databases.

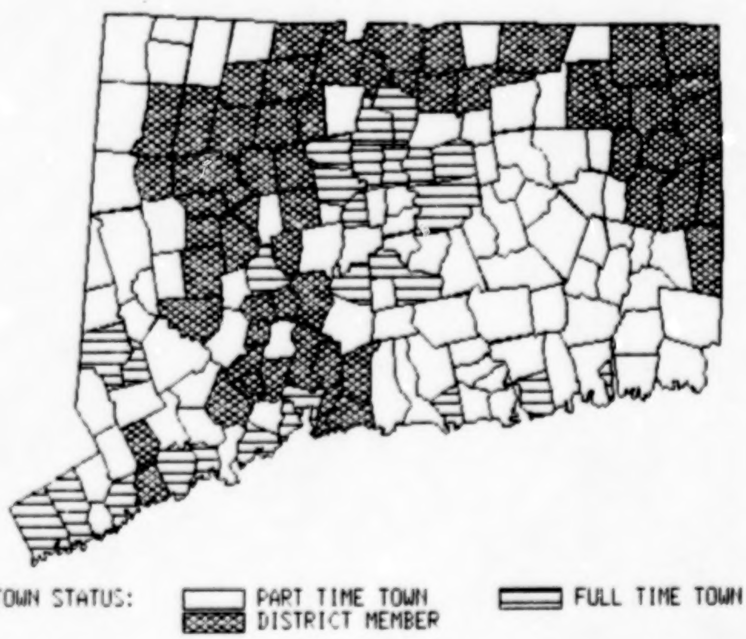

Figure 2. Local health districts in Connecticut, August, 1986.

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This approach to database compilation is not usually the most cost-effective method in any case and can result in mutually independent databases organized in incompatible formats. The necessary databases can be compiled and maintained more effectively at the state level by the appropriate agencies who have the responsibility and jurisdiction over the respective thematic components. Under this approach, local health departments would tie into the archival files of the agencies to access the portion associated with their geographic domain. This requires the appropriate statewide data networks to be in place (Dobson, 1983).

Developing database networks for local health services delivery is particularly difficult because at least five distinct databases under the control of various public and private agencies must be integrated (Figure 3): 1) geographic base file; 2) population estimates; 3) vital statistics; 4) environmental hazards; and 5) health services delivery. An extensive geographic base file for the State of Connecticut is currently being compiled by the Department of Environmental Protection's Natural Resource Center operating on an ARC/INFO system. Vital statistics are recorded by the Department of Health Services while population estimates are maintained by the Office of Policy and Management. Data sources on environmental hazards are more difficult to isolate although the Department of Environmental Protection monitors water and air quality and sites of known envi-

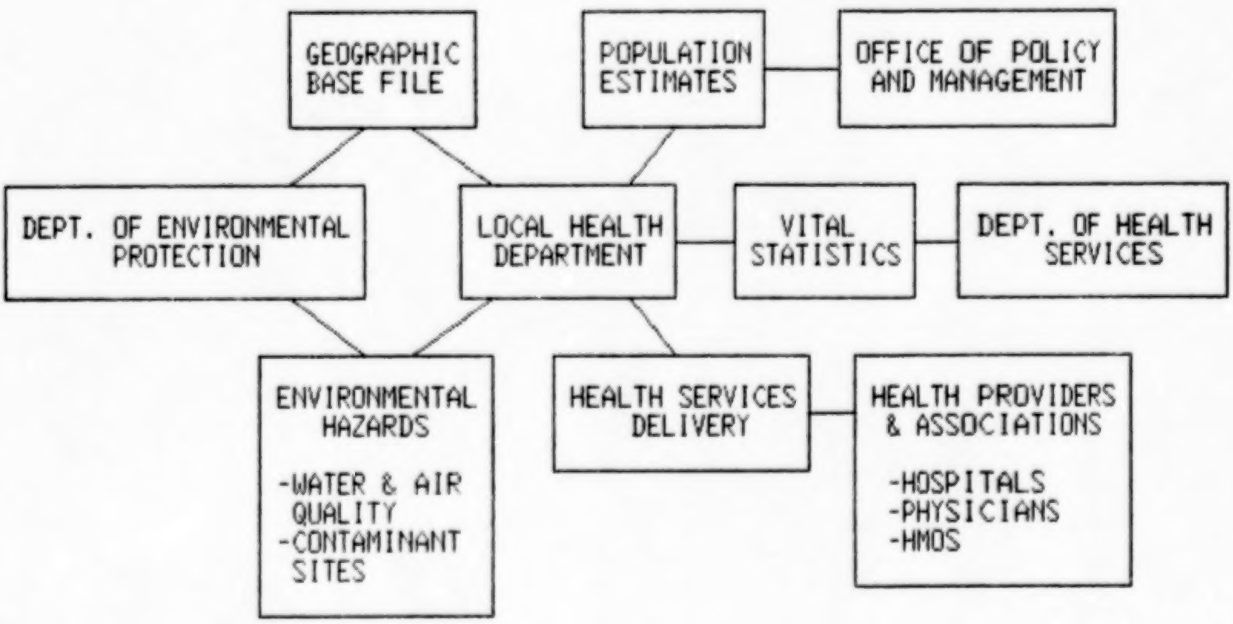

Figure 3. Database requirements and sources for local health planning.

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ronmental contaminants. Medical care records regarding health services delivery are the most diverse in number of sources and in some cases are property of the private hospitals, physicians, or group practices that provide and manage these services. Even when proprietary interests are not involved, data on health and medical needs may not be provided to local agencies at a level of disaggregation useful for decisionmaking and action. In Connecticut, the Department of Health Services has been most reluctant to release vital records for small populations or areas and to provide disaggregate data on the incidence of communicable diseases including AIDS. In every case, databases need to accessible at the most disaggregate level possible to provide for appropriate units of analysis for epidemiologic inquiry and to provide local decisionmakers the opportunity to aggregate information in a variety of ways to be responsive to town governments, school districts, and others agencies they serve. The importance of the availability of disaggregate data has been noted elsewhere in the context of general GIS development (Chorley, 1987).

5. CONCLUSION

Local health agencies and other units of local government concerned with service provision need geographic information to support their decision-making and service delivery functions. Although geographic information systems can produce the kinds of information agencies would find useful, the extension of GIS into local and regional health planning and services delivery poses problems that were not faced by agencies and corporations which first developed GIS technology. Local health agencies are not data-rich in the sense that the bulk of data they wish to analyze arises from their own operations or is otherwise easily captured. Even if these agencies had the staff to develop the databases for a GIS, agency-by-agency implementation would not necessarily be advantageous.

Data of relevance to health services planning and delivery are available but must be compiled from a variety of sources. Developing networks for accessing centralized databases from remote localities is a requirement for integrating secondary information on-line. Although these networks are envisioned by the leading state agency in GIS development, the state's current system cannot support a large number of remote users. To support network development at the local end, agencies need to develop expertise in GIS concepts and methods through training, development of databases for the limited range of medical services they directly provide, and purchase of equipment. These activities will provide the basis for extending GIS to local health services delivery and planning as the development of automated information systems at the state level proceeds.

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